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HELMET MOUNTED DISPLAY FEASIBILITY MODEL

John H. Allen and Richard C. Hebb
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FINAL REPORT February 1983

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A feasibility model of an advanced visual display system for flight simulation is described. The feasibility model is comprised of a video projector mounted on a pilot's helmet which projects a computer generated image onto a spherical screen. The video projector utilizes a laser light source in forming the projected video raster. The display is slaved to the viewer's head pointing direction via a magnetic head tracking device, and results in imagery that is generated and displayed for the instantaneous viewing

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direction of the observer. Since the computer image generator requires a measureable period of time to create an image for a specific head pointing direction, an undesirable display orientation error is induced each time the viewer moves his head. A method of continuously compensating for this image display error was provided and is described. This feasibility model has demonstrated successfully, on a small scale, the helmet mounted display concept. This concept will be utilized in a full scale development model scheduled for delivery under contract in 1985.

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CONSIDERATIONS FOR A VISUAL SIMULATION

In general, the need for improved high resolution, wide field of view displays in visual simulation systems exists because of the increasing necessity for training combat missions in flight simulators. Total duplication of the rich visual environment present everywhere outside the cockpit during actual nap of the earth missions or any other low level mission, though, is not possible using current visual simulation technology. Nor, in all probability, will it ever be. Due to technological and physical restrictions a visual display is only a representation or simulation of the actual visual environment. The choice of what should be simulated and how it should be done is not easy due to the number, nature and variety of visual cues available to and used by a veteran pilot during the performance of an actual mission. Until our understanding of the human visual system and its interactions with the real world are more complete, visual simulation systems will be designed to provide as much realism and fidelity as is possible with available funding and technology. Under these conditions, it seems reasonable to conclude that a display which provides eye limited resolution and high detail over the entire available field of view will supply the essential elements of a fully adequate visual simulation system.[1]

Typically, a high resolution, wide field of view display is created by butting together several computer generated video displays. Each display is separately created by a single image generator channel feeding video to either a video projector or to a conventional CRT monitor. The displayed video image is derived from a digital representation of a mathematically modeled landscape or gaming area depicting the training scene. This digital portrayal is more simply known as a data base. Depending upon the particular training requirements, the data base may be modeled from existing terrain information from some known location or, it can be entirely ficticious. In the usual case, then, a wide field of view visual simulation system consists of a number of video displays and their associated computer image generator channels, each channel obtaining visual information from a common data base. For a given area of visual display, or equivalently, field of view, increasing the number of the video displays and image generator channels improves the resolution of the whole display and increases the quantity of detail available to the viewer. Unfortunately, the visual simulation is improved at the expense of doing so with a more costly, complicated visual simulator system.

Another method of providing a wide field of view display with high resolution and detail utilizes a movable high resolution inset display. Two prin-

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1. Statler, Irving C. Characteristics of Flight Simulator Visual Systems, NASA, Washington, DC 20546 and U.S. Army Aviation Research and Development Command, St. Louis, MO 93166. NASA Tm.-81 278, or AVRAD COM Technical Report 81-A-8, April 1981, pp. 1, 2, 56, 57.

cipal types are target tracked (moved to follow some displayed target) and head/eye tracked (moved to follow the observer's head and eye position).

A target tracked display is usually projected upon or inset into a background low resolution, wide field of view display. In this way, imagery for the entire visual simulation can be furnished by a two-channel image generator, one channel driving the movable high resolution display, the other sourcing the low resolution background display. The position of the target tracked display that is within the background display is a function of target location. In other words, the display is servo driven in some manner so as to place a target image in the proper position within the background display. Target imagery can consist of an enemy missile site or even an accompanying friendly aircraft. Its visual content is entirely dependent upon the simulated mission. The advantages of this visual simulation system is that it provides some of the benefits of wide field of view and high resolution using a limited number of image generation channels. The primary disadvantage to such a system is that each additional high resolution object/target that is to be displayed requires still another target tracked high resolution display and image generator. As a result of this constraint, a target tracked display may be inefficient for certain kinds of training tasks.

A head/eye tracked display is tracked or moved about in direct response to the trainee's head and eye pointing direction. The visual display appears only where the observer happens to be looking. Further, if the display area is large enough to cover the observer's field of view, a visual simulation can appear to take place throughout the available viewing volume of the simulator, while in fact, the actual display covers only the immediate area available to the viewer. If a second smaller display, also head and eye tracked, is inserted at the center of the display mentioned above, high resolution imagery can be made available to the viewer along his line of sight. Since the human visual system detects high resolution imagery only in the small central foveal region of the eye, proper design of a two-channel head/eye tracked visual display results in the illusion that a high resolution, wide field of view visual simulation is omnipresent.

When the NAVAIR funded Helmet Mounted Display task started in 1978, its primary goal was to determine the feasibility of developing a fully operational dual channel, head/eye tracked, pilot helmet mounted display. Through the efforts of an in-house team a preliminary prototype or feasibility model was designed and built. Successfully demonstrated at a preproposal conference in November 1981, the feasibility model served as a test bed for many concepts, some of which were included in the specifications for the advanced development model, the Visual Display Research Tool, now in the procurement cycle.[2]

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2. For additional information on the advanced development model, see articles entitled "Helmet Mounted Laser Projector" in the Proceedings of the 1981 Image Generation Display Conference II (AFHRL) and the 3rd Interservice/Industry Training Equipment Conference.

The Visual Display Research Tool, 6.3 funded by NAVAIR, is targeted for incorporation into the Visual Technology Research Simulator (VTRS) in early 1985. This advanced visual simulation system contains only two computer generated displays, yet it provides both a wide angle field of view and high resolution. The high resolution inset display contains high detail scene content and is presented only at the observer's point of gaze or, equivalently, area of interest. The surrounding low resolution display, containing low detail scene content, fills the remainder of the observer's field of view. Visually, the composite display will tend to match the acuity profile of the human eye by generating high resolution imagery only along the foveal axis, and low resolution imagery in the periphery.

An artist's concept of the proposed system is depicted in Figure 1. The flight simulator cockpit is enclosed by a spherical screen. Two displays are projected onto the highly retro-reflective interior surface of the sphere. The scenes in both the high resolution Area of Interest (AOI) display and the surrounding Instantaneous Field of View (IFOV) display are computer generated according to the pilot's line of sight. His line of sight, with reference to the ground, at any one moment in time, is a consequence of his cockpit referenced head and eye position, as well as the attitude and position of the simulated aircraft. Each display is an interlaced video raster composed of 1023 horizontal scan lines. Instead of being projected by a conventional high resolution video projector, though, they are formed from video modulated laser beams which are projected and scanned from the pilot's helmet.

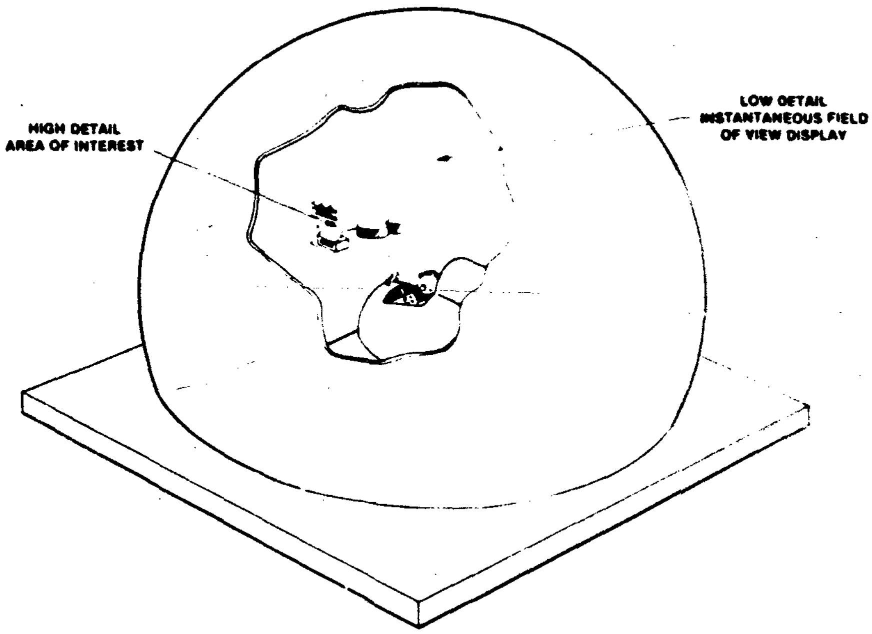

Figure 1. Artist's Concept of an Area of Interest, Instantaneous Field of View Dome Display.

A computer image generator channel generates a blue, a green and a red video signal to form the full color visual scene within each display. Six video signals are required for the two displays, two of each color. Each of the video signals drives an acousto optic modulator. The six acousto optic modulators, in turn, modulate the intensity of two blue and two green laser beams from a remotely located argon laser, and two red laser beams from a companion dye laser. The three modulated, red, green, and blue laser beams that form each of the two displays are optically combined so as to create a single composite full color, beam for each display. Each of the two composite beams are then arranged so as to strike the facets of a rotating high speed scanner mirror. Here the composite beams for each display are horizontally line scanned. After being formed, the line scans for each display are then suitably focused onto the polished ends of two coherent flat fiber optic ribbon cables for subsequent relay to the helmet mounted projector.

The far end of each flat fiber optic ribbon is attached to the pilot's helmet. There, the two separate, full color line scans emerge and are vertically frame scanned by oscillating scanner mirrors as they are projected onto the interior surface of the spherical screen.

The display that the pilot/trainee's attention will be most focused upon, the Area of Interest (AOI), will occupy a viewing area of approximately 25 degrees square and will resolve approximately 3 arc minutes per TV line pair. Covering the surrounding display area, the Instantaneous Field of View (IFOV) fills a 125-degree horizontal by 110-degree vertical viewing volume. The resolution of the larger display changes across the field, but the average is approximately 15 arc minutes per line pair. In order to smooth the abrupt transition from one display into the other, the two displays are blended with each other in a 5-degree blend region within the border of the Area of Interest (AOI) display. Blending of the displays is accomplished by gradually reducing or increasing the brightness of the AOI within the blend region, and simultaneously increasing or reducing the brightness of the IFOV. In this way, equal luminance is obtained throughout the blend region as one display gradually fades into another. Further, the blending should reduce or eliminate any visual artifacts caused by low detail, low resolution data base models changing into high detail, high resolution data base models when the transition is made between the IFOV and AOI.

The pilot's head and eye positions are determined by lightweight helmet mounted head and eye trackers. A fixed emitter, helmet mounted sensor system determines azimuth, pitch and roll of the pilot's head with respect to the simulator cockpit. An invisible, infrared light source illuminates the pilot eye. His vertical and horizontal eye position is determined by imaging the reflected infrared light from his eyeball onto the face of a helmet mounted, infrared sensitive detector. The digital outputs from both trackers are vectorially combined in order to form the cockpit referenced pilot viewing direction. This viewing direction is combined with the instantaneous attitude and position of the simulator aircraft within the data base to arrive at a data base (ground) referenced pilot line of sight for which the image generator creates a visual display.

SECTION II

THE HELMET MOUNTED DISPLAY FEASIBILITY MODEL, SYSTEM OVERVIEW

In order to investigate the technological areas of risk, and, to a somewhat lesser extent, determine the psychophysical requirements for the proposed Visual Display Research Tool (VDRT), a small helmet mounted display feasibility model was designed and built in-house.

The feasibility model, known in-house as the Helmet Mounted Display or HMD, was not as elaborate as the previously described VDRT. Instead of two full color head and eye tracked displays, the HMD produced only a single monochromatic head tracked display. Like the proposed VDRT, the HMD was a laser scanned, helmet mounted visual display system.

An artist's sketch of the completed feasibility model is shown in Figure 2. A six-watt water-cooled argon laser provides a green laser beam which is intensity modulated by an acousto optic modulator (AOM). The video information used to drive the modulator is produced by one channel of a dual channel computer image generator (CIG) which derives its information from an appropriate data base. The video modulated laser beam is collected,

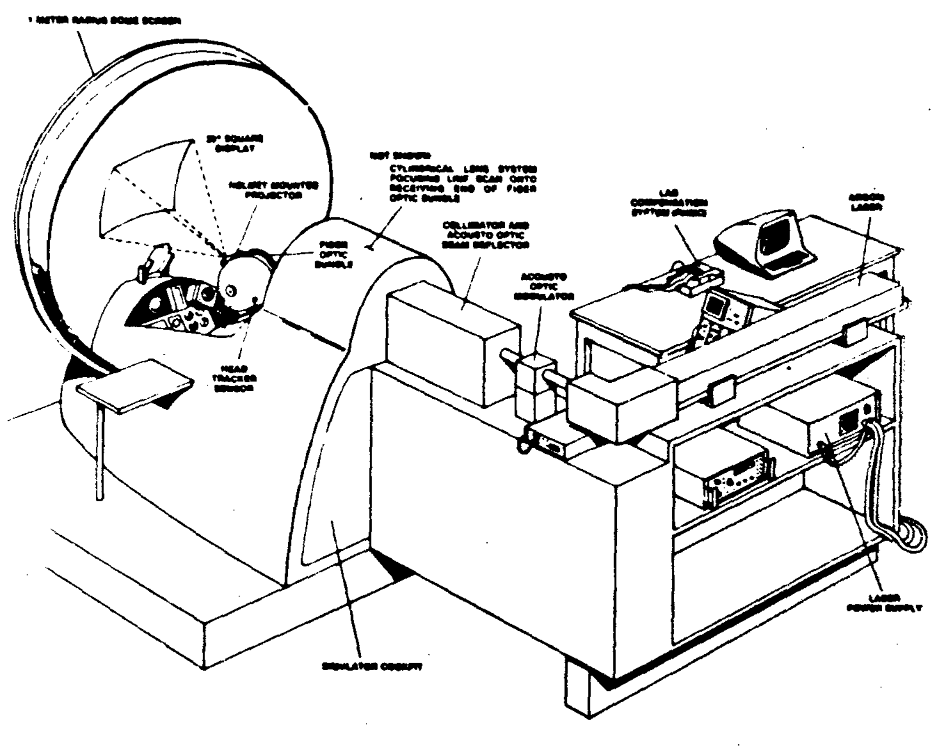

Figure 2. Helmet Mounted Display Feasibility Model.

collimated and shaped by a lens system so that it fills the aperture of an acousto optic beam deflector (AOBD). Here, the horizontal line scans which eventually form the displayed video raster are formed. The video modulated, horizontally scanned beam is again collected and focused by another series of lens elements onto one polished end of a coherent fiber optic ribbon bundle. The opposite end of the flexible two meter bundle is attached to the observer's helmet. Emerging from the helmet end of the fiber optic bundle, the line scan is projected towards a helmet mounted scanning gavonometer mirror which optically deflects the line scan onto the retro reflective interior of the surrounding dome screen. As it moves, the scanning mirror sweeps the fully formed horizontal laser line scans downward on the screen, completing the displayed video raster.

Head pointing direction (HPD) is provided by a helmet mounted sensor, cockpit mounted emitter system. Electromagnetic fields radiated by the emitter are coupled into the sensor and by processing the signals obtained from the sensor, head orientation is determined.

Since flight dynamics are not included, and the cockpit controls are inactive, no simulation of an actual aircraft is possible; however, a simple joystick allows the viewer wearing the helmet to change his relative coordinates and attitude within the visual data base. The subject, then, does have control over the cockpit location and attitude within the simulated visual environment.

Before the image generator creates the display, the line of sight of the cockpit seated observer is determined. Both head pointing direction and joystick position are sampled at a 60 Hertz rate and are vectorially combined by the computer image generator in order to determine the instantaneous line of sight that the display will be created for.

Production of the video imagery filling the viewer's display requires a certain amount of processing time. The displayed video raster consists of a single video frame which is composed of two interlaced video fields. A single video field requires approximately 67 milliseconds of processing time, 16.7 milliseconds of which are for scanning and display. The video fields are produced one after the other at a 60 Hertz rate, but delayed by the 67 milliseconds processing time. To combat this induced image generator lag, a compensation system was designed and fabricated to place the viewed display along the old line of sight it was created for rather than projecting it at the observer's current line of sight.

The viewer wearing the Helmet Mounted Display sees a square video display which always remains in a forward viewing position regardless of head position. The contents of the display are updated according to where the viewer is looking and what commands the joystick is given. The appearance is much like a green tinted window that is free to move about in response to head movement.

This system is not optimal. Certain components have been judged to be unacceptable for the final system. Some approaches which initially appeared feasible proved to be cumbersome but remained in the helmet mounted display feasibility model only for the sake of system continuity. A more critical detailed examination of the system follows in the next section.

SECTION III

FEASIBILITY MODEL SYSTEM DESCRIPTION

In this section, the major systems involved, their basic components, and their inter-relationships will be addressed.

IMAGE GENERATOR

The completed feasibility model utilizes a General Electric Compuscene Computer Image Generator (CIG) which was made available from NAVTRAEQUIPCEN's Visual Technology Research Simulator (VTRS) facility. The CIG provides a real-time video image of a digitally stored environmental data base to the helmet mounted laser projector.

The Helmet Mounted Display Feasibility Model relies upon the CIG to create the visual simulation contained within the display. The CIG provides the visual imagery that is updated at a 60 Hertz video field rate to reflect changes in the observer's head pointing direction (HPD) within the cockpit as well as changes in the simulated cockpit attitude and location within the environmental data base. In the Helmet Mounted Display (HMD), the visual display is not in a fixed location with respect to the simulator cockpit. If it were, the image contained within the display would be a direct result of the movement of the joystick by the observer. Insteau, the head tracked visual scene is projected in the direction the pilot-observer happens to be looking and is updated according to both head and cockpit/joystick movement.

All of the visual scenery displayed by the HMD is the end result of processing the information contained within an environmental data base. In general, environmental data bases are composed of a number of two- and three-dimensional objects or models depicting, in a mathematical fashion, ground and cultural features. It is sufficient for the purposes of this report to consider a model to be composed of a number of flat polygons called faces. The perimeter of each polygon is composed of a number of short line segments which are joined at several points called verticies. A model is defined by the location of its verticies within the data base; the more complex a model is, the greater the number of faces and vertices it contains. In addition, each face is assigned three values representing the amounts of red, green and blue comprising its color and brightness.

The data base contains two types of coordinate systems, fixed and moving. The fixed coordinate system serves as the reference system and uniquely locates every object within the data base. A moving coordinate system is also referenced to the fixed system, but is assigned to the pilot-observer's joystick. By manipulation of the joystick, the observer is actually altering the position and orientation of a moving coordinate system within the environmental data base.

As an observer moves his head, he changes his head pointing direction which is provided by the head tracking system. Equivalently, he is altering the orientation of a vector within the moving coordinate system. For ease in visualization, we can refer to this vector as the observer's line of sight.

Each television raster field output by the image generator requires three processing cycles. Running at a 60 Hertz update rate, each cycle requires approximately a field time or 16.7 milliseconds for completion. The cycles operate simultaneously on sequential television fields, outputting them at a 60 Hertz rate one after another in a pipeline fashion. Due to timing constraints between the first and second processing cycles, however, the pipeline process actually requires 4 field times or 66.7 milliseconds.

During the first cycle, the CIG retrieves the head tracker and joystick data, processes it, and determines the observer's position and line of sight. Visual fading factors derived from this data, fog and other environmental effects, are also determined.[3] The data is not ready until 5 milliseconds into the next cycle, so it is held over one additional cycle until the start of the next full second cycle.

In the second cycle, position and line of sight data are utilized to determine the objects that are visible within the data base. Priorities are resolved (which object obscures which), and the verticies of the visual models are mapped onto a two-dimensional display plane which lies normal to the observer's line of sight. The size of the display plane or view window is determined by the physical size of the helmet mounted laser display - about 20 degrees square. Its rotation about the observer's line of sight is a consequence of head rotation. In addition, the second cycle computes sun angle, face shading and color. The data mapped onto the plane will eventually form the visual display.[4]

The third cycle completes the transformation from digital data to video. It receives a block of data in a raster line format indicating edges of faces, locatior, priority and color. Using the fading information and the data contained within the block, it generates one video field corresponding to the observer's field of view along his line of sight.[5]

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3. Morland, D. V. and Michler, F. A. System Description, Aviation Wide Angle Visual System (AWAVS) Computer Image Generator (CIG) Visual System, General Electric Company, Space Division, Daytona Beach, FL 32015. Technical Report NAVTRAEQUIPCEN 76-C0048-1, Rev. May 1981, pp. 44-50.

4. ibid., pp. 50-57.

5. ibid., pp. 57-67.

Figure 3 depicts the whole process in a timing sequence. During the first television field "0" the head tracker generates head pointing direction data, and along with the joystick data, it is transferred to the CIG for the start of cycle one processing during field "1". During field "2" the data generated by cycle one processing is buffered until the start of the next fullfield, field "3." Cycle two processing starts in field "3." The data block generated during field "3" is used during field "4" by the third processing cycle to output the video to the helmet mounted laser projector.

It is essential to understand that a video image being generated by the CIG is not displayed until 4 fields or 66.7 milliseconds after the point in time it was generated for. In essence, the image "lags" the point in time that the observer's line of sight and data base location were sampled. Without lag compensation for the image delay, the viewer will never see a correct display, and the illusion of flying through a scene with joystick control over position and attitude is lost.

Real aircraft dynamics are not included in this developmental system, instead, the joystick is used to represent movement of the observer's "aircraft" through the data base. Viewer HPD is provided by the Polhemus head tracking device, for which special hardware interfaces were designed and built to handle the data flow from the head tracker to the CIG. These interfaces provide the conversion and buffering of the data as required by the CIG data format and program timing.

LASER VIDEO PROJECTOR

Video imagery provided by the CIG is displayed by a laser video projector designed and constructed in-house. The system projects a 20 by 20 degree monochromatic TV raster display from a projector, mounted on a military flight helmet worn by the observer, onto the interior of a one meter radius dome. A beaded retro-reflective material covers the interior of the dome and provides high screen gains in the direction of the observer. The system is designed to operate at a 60 Hertz field rate, with the line rate adjustable for CIG video rates of 525 to 1023 lines per frame.

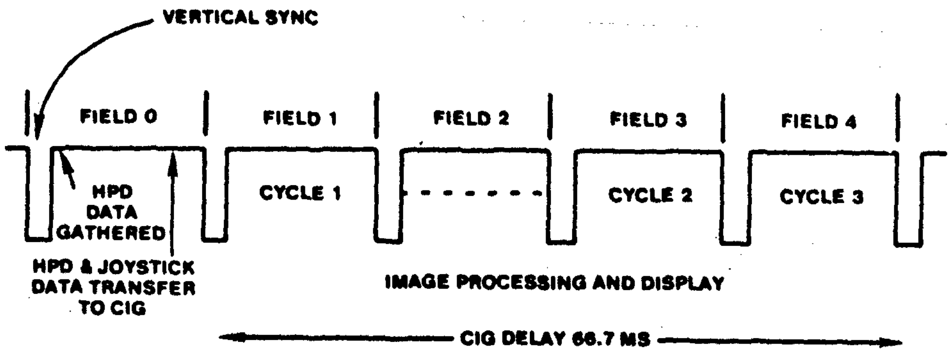

Figure 3. Processing Sequence for a CIG Display.

Figure 4 is a block diagram of the laser video projector. The major components of the projection system are as follows:

Argon Laser
Acousto-Optic Modulator (AOM)
Acousto-Optic Beam Deflector (AOBD)
Coherent Fiber Optic Bundle
Mirror Galvanometer Frame Scanner

Each one of these system components is discussed below.

The argon laser, a Control Laser Corporation model number 553, is operated in a monochromatic mode through the use of a Littrow prism as the rear cavity mirror, yielding a single green wavelength of 5145 angstroms. The laser beam has a diameter of 1.6 mm. and a divergence of 0.4 milliradians.

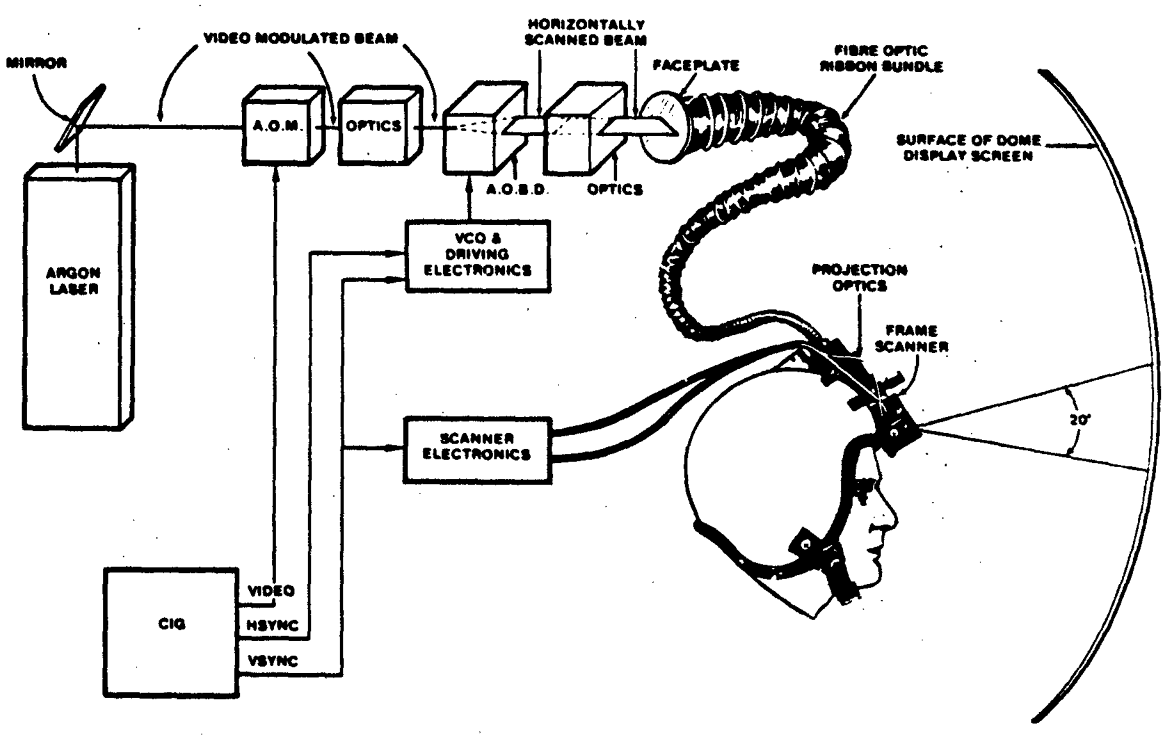

Figure 4. Block Diagram of Laser Video Projector.

The output of the laser is intensity modulated with video information from the image generator by an acousto-optic modulator, manufactured by the Intra-Action Corporation (model number 125).[6]

The video modulated laser beam is expanded by the use of a Tropel Beam Expander to a 22 mm. diameter collimated beam, and then compressed to a 22 mm. line by a cylindrical lens. This 22 mm. line is focused into the crystal of the acousto-optic beam deflector system, which deflects the first order diffracted beam through an angle of 30.6 milliradians, creating the video line scan.[7] The deflection of the beam is controlled by a 275 - 475 MHz frequency chirp centered at 375 MHz. The chirp, or frequency sweep, is provided by a voltage controlled oscillator (VCO) manufactured by Radio Development Laboratories. A voltage ramp controls the range of the frequency sweep, its linearity, and the time required to run a full sweep. Since the horizontal video line rate varies from 1023 to 525 lines per frame depending upon the resolution of the display, the period of the voltage ramp is variable from 25.6 to 63.5 microseconds.

The AOBD was manufactured by the Harris Corporation and is made of tellurium dioxide (TeO_2). Its maximum throughput efficiency of only 15 percent places a limitation on the brightness of the final display. In addition, in order to achieve a linearly deflected, focused beam from the AOBD, it must be driven by a linearly incremented frequency sweep.[8] In order to avoid unintentional modulation of the laser line scan by the AOBD, the output power of the voltage controlled oscillator must remain constant throughout the duration of the sweep. At the sweep rates required, the in-house designed driver for the AOBD is neither uniform in power, nor does it provide a linear sweep (the linearity required is about .01 percent). The end result is a severe loss of resolution, vertical intensity banding, and distortion in the final projected display. In Figure 5 these effects can be seen, with distortion appearing as a slight "S" shape in the normally flat runway.

After the AOBD, the beam is recollimated by the use of a second cylindrical lens to reform the 22 mm. diameter beam. A focusing lens is then used to focus the beam down to an approximate 20 micron spot size, which, due to the scanning effect of the AOBD, results in a 10 mm. wide line scan.[9]

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6. Maldonato, E. D. Helmet Mounted Display Feasibility Model, Optical Design. Technical Report NAVTRAEQUIPCEN IH-340, July 1982, pp. 6-8.

7. ibid., pp. 9-15.

8. ibid.

9. ibid., p. 16.

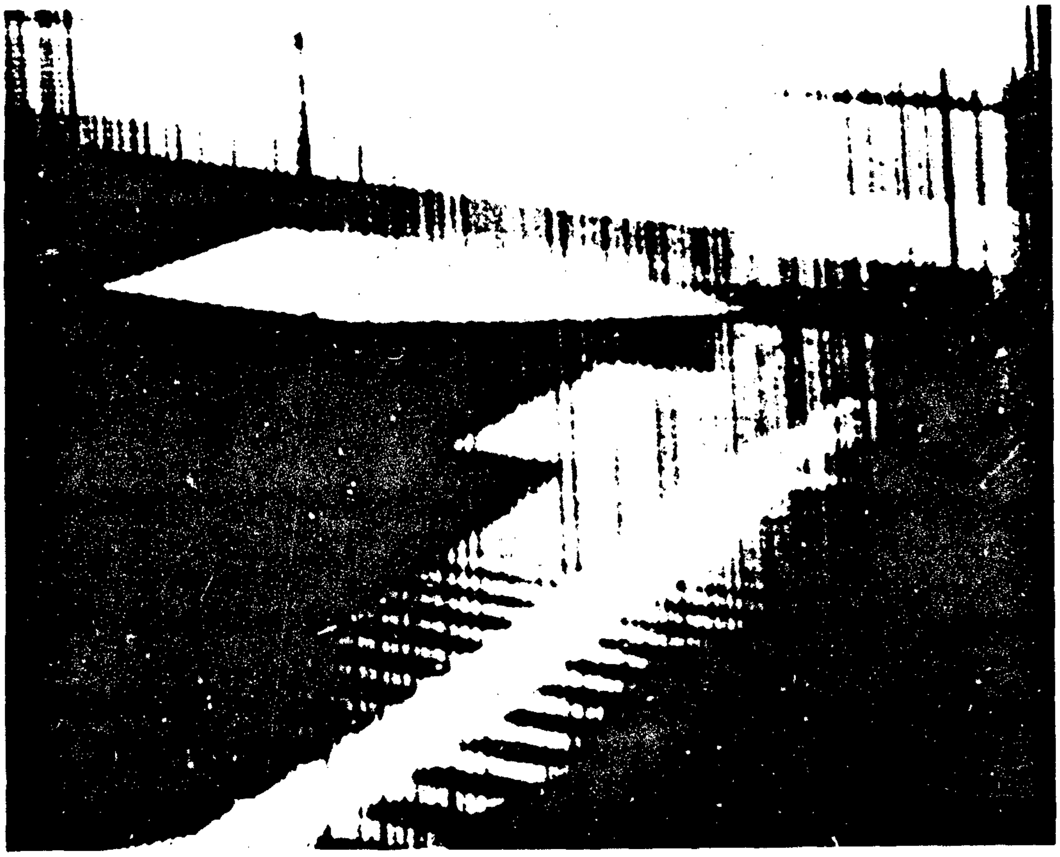

Figure 5. Displayed TV Raster as Viewed From Cockpit.

This line scan is arranged to fall on the polished faceplate of either a full frame fiber optic bundle or a flat ribbon fiber optic bundle depending upon the particular setup in use. Both coherent bundles serve the same purpose, which is to optically transport the laser line scan to the observer's helmet. The full frame coherent fiber optic bundle is manufactured by the American Optical Company. The bundle consists of individual 10 micron fibers drawn in 5 by 5 arrays which are then arranged into a rectangular grouping with dimensions of 10 mm. by 8 mm. on the faceplates. Each fiber is one meter long and has a numerical aperature of 0.56. Transmission through the bundle is limited to approximately 45 percent and mobility of the helmet mounted projector is somewhat restricted due to the stiffness of the bundle. A flat coherent fiber optic ribbon manufactured by Galileo Electrooptics Corporation is also being used. A number of 6 by 6 arrays of 10 micron fibers are arranged in a 2-meter long ribbon that is 12 fibers thick and 1002 fibers wide. The numerical aperature is .68. Mobility is much improved over the previously described "full frame bundle," although the irregularity of the fiber spacing and the number of broken fibers further reduces the resolution, and places dark vertical stripes on the display (see Figure 5.)

The second face of the fiber bundle is mounted to the helmet and arranged to lie in the focal plane of a 15 mm. projection lens. After the projection lens, the laser line scan encounters a closed loop, moving iron galvanometer mirror scanner obtained from General Scanning, Inc. (model number 100PD). Servo controlled by a General Scanning controller (model number CCX-102), and driven by the 60 Hertz vertical sync from the CIG, the scanner mirror deflects/sweeps the laser scan lines vertically as they are projected onto the interior surface of the dome screen, providing the vertical scanning required to form the completed TV raster previously referred to in Figure 5.[10]

HEAD TRACKER

The head tracker, a SHMS III-A procured from Polhemus Navigation Sciences, Inc., computes the observer's head pointing direction with respect to the simulator cockpit. Known in-house as the Polhemus head tracker or "PHT," the basic system consists of a magnetic field radiator, a magnetic field sensor and a controller - the electronic systems unit. Mounted on the observer's helmet, the small, lightweight sensor moves within a magnetic field generated by the cockpit mounted radiator. As the orientation and position of the helmet mounted sensor changes, the magnetic field coupling between the emitter and sensor also changes.

The sensor as well as the radiator each consist of three small orthogonal coils. Excited sequentially by a 10.6 kHz. frequency burst, the radiator produces three magnetic fields whose axes are orthogonal to each other. Each orthogonal radiator coil emits a magnetic field for a small period of time and, during the time the field is active, each one of the sensor coils is sampled.

The field generated by the active radiator coil is symmetrical about an axis that coincides with the axis of the radiator coil. The orientation and position of each sensor coil within the generated field determines the amount of current induced to flow in the sensor coil. By performing a mathematical operation upon the signals obtained from the three sensor coils, the sensor's orientation relative to the axis of the emitting field can be determined. Its position relative to the axis is not yet fully determined due to the symmetry of the field about the axis. This operation is performed three times, once for each field generated. When the above operation has been performed for each of the three radiated fields, the position and orientation of the sensor relative to a three axis coordinate system can be determined.

The sequence which determines the position and orientation of the sensor relative to the radiator is an iterative process which is initiated by the vertical sync signal once every 16.7 ms. Figure 6 depicts the process in a general fashion.

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10. ibid., p. 18.

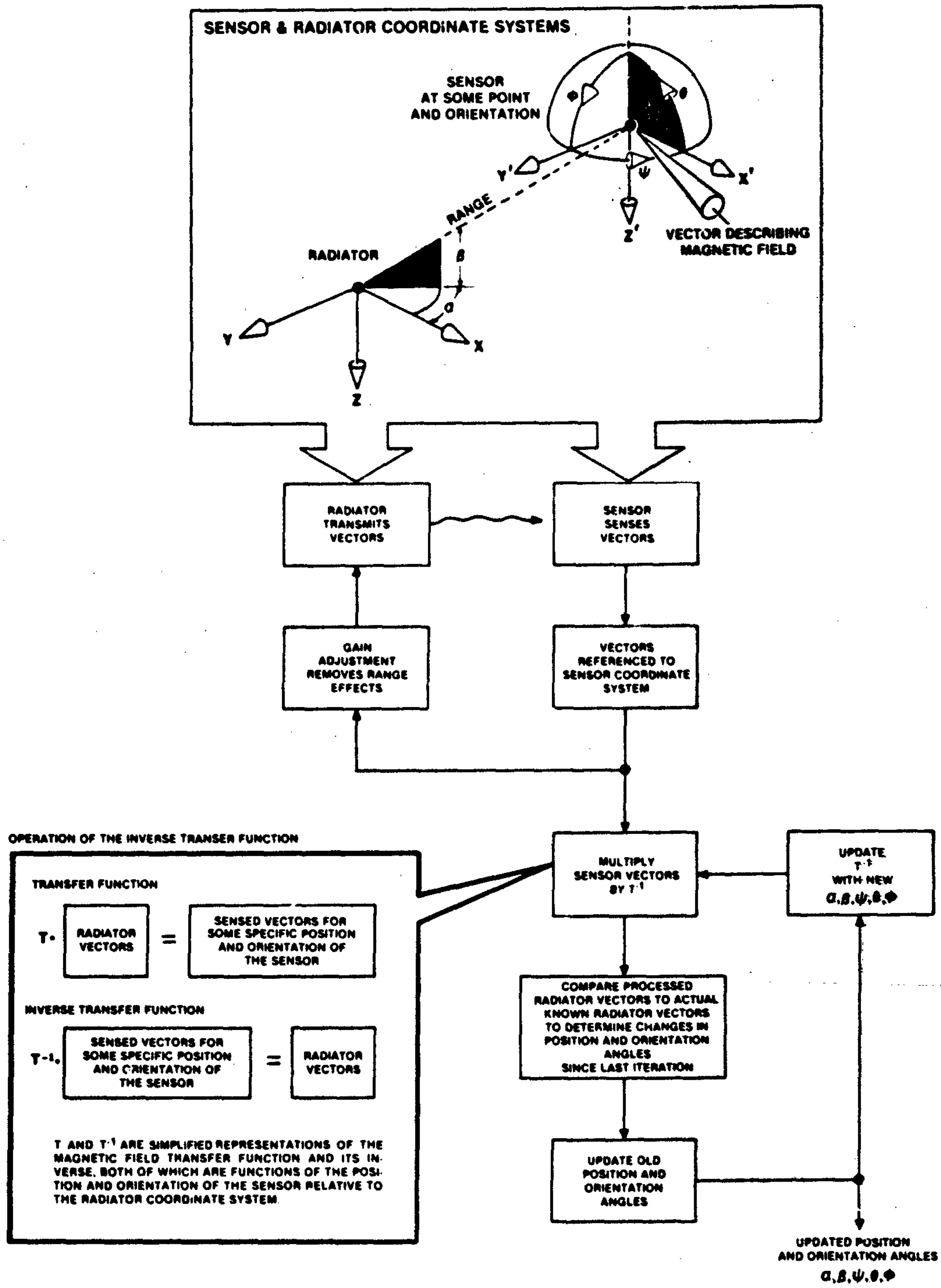

Figure 6. Basic SHMS III-A Processing

The magnetic field generated by a radiator coil oriented along the "X" axis (the observer's forward axis) for instance, can be described at some arbitrary point as a vector referenced to the radiator coordinate system. The sensor, which happens to be located at that point, will have different currents induced in its coils by the field. These currents will describe the vector in terms of the sensor coordinate system. Each time a radiator coil becomes active and generates a field, it is described by the sensor coordinate system, arbitrarily located at some point within the field, as a vector. After the three fields have been emitted sequentially, and described in terms of three vectors referenced to the sensor coordinate system, they are operated upon by an inverse magnetic field transfer function.

For simplicity, the inverse transfer function will not be described in any great detail. Instead, it will be described as a mathematical operation that is a function of sensor position (alpha and beta) and orientation (psi-azimuth, theta-pitch, and phi-roll) with reference to the radiator coordinate system. For a given current, driving a radiator coil with some fixed dimension and number of turns, there is an associated magnetic field. This field can be fully described, using a suitable coordinate system, as a vector at any point distant from the coil. In a like manner, the three orthogonal fields generated by the radiator are also fully describable at any point with reference to the radiator coordinate system. Suppose a second moving coordinate system, the sensor coordinate system, is introduced. As long as its orientation and position with respect to the fixed radiator coordinate system is known, the field vector can also be described in terms of the moving sensor coordinate system. Figure 6 depicts a mathematical operation on the vector which is in terms of the radiator coordinate system. The output of this operation is the vector in terms of the sensor coordinate system. The operator is the transfer function "T" which is a function of position and orientation of the sensor with respect to the radiator. If the output of the previous operation is operated upon by the inverse transfer function, "T-1", the result is the vector with respect to the radiator once again. In effect, the inverse transfer function has undone the previous operation.[11]

Looking at Figure 6 once again with particular attention to the processing sequence, the vectors as referenced to the sensor are multiplied by the last known correct inverse transfer function, using the last known alpha, beta, psi, theta, and phi. The output of the operation, if the position and orientation are correct, is the characteristic field known to be emitted by the radiator. If the last alpha, beta, psi, theta and phi are incorrect, the outputs are not the correct field vectors with respect to the radiator, and the difference is linearly related to the true alpha, beta, psi, theta and

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11. Anon. Operation and Maintenance Manual for the SHMS III-A, SPASYN Helmet Mounted Sight, Polhemus Navigation Sciences, Inc., Post Office Box 298, Essex Junction, VT 05452. November 1980, OMN-1024-1, pp. 4:1-4:18.

phi. The new position and orientation angles are computed and output, and the inverse transfer function is updated for the next iteration. Range is determined by adjusting the current to the radiator coils and/or sensor gain in such a manner that the vector measured by the sensor always has some constant length. A more rigorous treatment of the processing sequence may be found in Reference 12.

In the HMD system, the sensor is mounted on the helmet and the radiator placed immediately behind the cockpit seat. Hence, sensor orientation is analgous to head orientation or more concisely, HPD.

As previously described in the section entitled "Image Generator" (page 12), the cockpit referenced HPD is used by the CIG to compute the observer's line of sight. Although both position and orientation of the sensor are provided by the SHMS IIIA, only the sensor orientation is used to determine the observer's line of sight. Strictly interpreted, this simplification is not mathematically correct. It is simply expedient, since in the case of the feasibility model, the extreme range at which objects within the data base are typically viewed precludes the visual effects of minor head translation.

Because the head tracking system relies upon magnetic field coupling, there are limits to the extent of the radiator/sensor separation. This is referred to in Polhemus literature as the "motion box." The range extends 16 inches forward of the radiator (X direction), plus or minus 8 inches from side to side (Y direction) and 8 inches downward from the radiator (Z direction). Operation outside these limits results in performance degradation. When the head tracker is installed in the Helmet Mounted Display Feasibility Model, the following performance specifications are met:

STATIC ANGULAR ACCURACY
plus or minus .5 degrees at 50 percent CEP
(50 percent of the time, the output is within +/- .5 degrees)

ANGULAR JITTER
1/10 degrees peak to peak (roughly equivalent to 1 bit out of 12 bits)

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12. Raab, Fredrick H.; Blood, Ernest B.; Steiner, Terry O.; and Jones, Herbert R. Magnetic Position and Orientation Tracking System, in IEEE Transactions on Aerospace and Electronic Systems, Vol. AES-15 No. 5, September 1979, pp. 709-718.

UPDATE RATE synchronized to CIG 60 Hertz video field rate (SHMS IIIA can free run at faster rates, however, cycle time is irregular) DYNAMIC ANGULAR ACCURACY for normal head rates (600 degrees per sec or less) essentially defined by the number of degrees that the head moves during the 16.7 ms. required to compute HPD.

Formatted serially, the digital data consists of six 17-bit words output in the following order: yaw, pitch, roll, X (forward direction from the radiator) Y (lateral movement), and Z (vertical motion). The first 12 bits of each 17-bit word are significant data, the next 4 are noise, and the last bit is a parity bit. The hexadecimal values for the rotational data are as follows:

HEX VALUE

	C000Hex	8000Hex	4000Hex
Yaw	Right 90 degrees	Center	Left 90 degrees
Pitch	Up 90 degrees	Center	Down 90 degrees
Roll	Right 90 degrees	Center	Left 90 degrees

About 14 to 15.5 ms. after the initial sampling procedure, the SHMS III-A provides a "data ready" pulse. This is a signal to the interfacing hardware that the processing is complete, and the head pointing direction (HPD) data is available. In the current configuration, the in-house designed interfacing hardware clocks out the data before the beginning of the next sync pulse (vertical sync) which occurs every 16.7 milliseconds (see Appendix). This sync pulse starts a new HPD data gathering cycle. During operation, the head tracker delivers HPD data at a 60 Hertz rate with a delay of approximately one field time between the sampled HPD and the HPD data output.

IMAGE LAG COMPENSATOR

During the development of the feasibility model, the problem of scene instability quickly became apparent. Without compensation, due to the time required for head tracker and CIG computations, there exists an error in image placement during head motions. Since the problem is especially apparent during a rapid head movement by the observer/pilot wearing the helmet mounted projector, the solution to this problem came to be known as Rapid Head Motion Compensation (RHMC). The compensation mechanism involves the use of a micro-processor with software that controls the relative projection angle of the imagery from the viewer's helmet in response to image displacement error. Change in the image projection direction is accomplished via offsets input into the vertical and horizontal sweep of the laser video projector. In this section, an examination of the cause, effects, and the solution devised for scene instability will be discussed.

The problems that arise from rapid head motions are due to the discrete sampling of the head pointing directions and the finite time involved in providing an updated image via the CIG. This results in an image placement error coinciding with head motion and is manifested in an apparent motion of what should be stationary objects in the subject's FOV. With no compensation, objects appear to "swim" during the start and finish of a head motion and are displaced during the actual head motion.

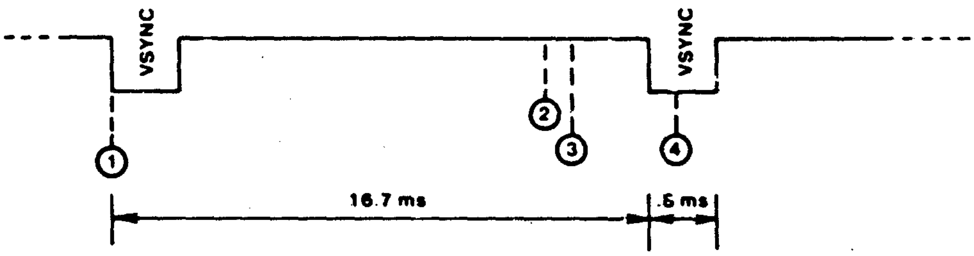
Consider the viewer to be at some stationary position within the data base. Further, consider the head of the viewer to be stationary with an image projected onto the screen from the HMD. Objects within the displayed image are stable as long as the viewer does not move his head because the displayed image is being computed and displayed for a fixed line of sight. Returning to Figure 3, when the viewer changes his head pointing direction (HPD), at the start of field "0," the head tracker doesn't compute a new HPD until just before the next vertical sync. This new set of yaw, pitch, and roll data reflects the HPD of the viewer at the sampling time, not at the time of the HPD output. The time between the sampling and output of the HPD data, one field time or 16.7 ms., is one source of delay in updating the image. Another source of delay in updating the image after the occurrence of a head motion is the time required for the CIG to take in new head pointing data and then to compute an image based on the new viewer line of sight. As previously described in the "Image Generator" section, the CIG requires 4 fields to generate and display the image.

If the viewer has moved his head during the five field times that occur between HPD sample time and the display of the image based on that sample, he will observe an incorrectly displayed image. A 5 field, or 83.5 ms., time lag exists between the old line of sight the image is created for and the current line of sight the image is being projected towards.

To visualize the effects of the 83.5 ms. time lag, suppose that the projected image contains a tree as an object in the center of the display. Without compensation, a head motion to the right of 2 degrees during the above time interim between sampling and display will result in the tree also moving 2 degrees to the right. All objects in the image will retain the same orientation they had before the head motion and the scene will be incorrectly displayed until the process of computing a new HPD and subsequent CIG image display for the new line of sight is completed. When the viewer completes the head motion, the tree will at that moment be displaced to the right followed by a gradual movement of the tree to the left as the CIG generates the correct image for that particular line of sight. Obviously, this effect can be very disorienting to the viewer, for trees should be rooted in the ground and stationary. Not only objectionable from a subjective standpoint, it is highly probable that an improperly placed image can result in negative training cues to the prospective trainee. As a consequence, it is desirable that the image lag be reduced to some tolerable level.

The Rapid Head Motion Compensation System reduces the previously described image delay problem. Essentially the hardware, under software control, moves the raster in such a manner as to keep objects in the FOV from moving as the pilot changes his HPD. The RHMC system performs compensation based on the current HPD sample compared with the HPD that was used to compute the image to be displayed next. The difference between these HPDs is massaged by software and sent to raster shifting hardware to shift the projected imagery horizontally and vertically opposite the direction of head motion. The system attempts to place the display physically along the old line of sight it was created for.

For the HMD feasibility model, the angular error in line of sight amounts to the movement of the viewer's head over five video field times. The software that corrects this error has been named "5THPREV," referring to the number of video fields delay involved. The software is written in 8085 assembly language and is designed to provide raster shift values within the timing restraints shown in Figure 7 (see Appendix A for flowcharts and additional detail). This timing diagram shows the initialization of the PHT data gathering and calculation cycle by the vertical sync of the video, followed by a "data ready" some 15 milliseconds later. The software then takes the HPD from the PHT data controller (see Appendix A) and, after processing, outputs the raster shift values before the next vertical sync. In general, the program is configured to allow compensation for any number of "fields" delay (depending on the specific CIG delay) and is referred to as "NTHPREV."



1 → 2 PHT PERFORMS MEASUREMENT AND CALCULATION PROCESS. (15.5 ms)

2 → 3 H.P.D. DATA IS READY AND ACCEPTED BY 8085.

3 → 4 SHIFTING VALUES ARE CALCULATED. OUTPUT OCCURS AT 4

4 → 2 STORAGE TABLES ARE SHIFTED 8085 WAITS FOR PHT DATA READY.

Figure 7. RHMC Timing Diagram.

A graphical illustration of the effects of compensation on the display is provided by the graphs in Figure 8. Consider the simulator cockpit to be fixed at some point within the environmental data base used to create the visual display and for simplicity, consider all angular motion relative to the simulator cockpit. In the first graph, an arbitrary horizontal head movement by a viewer wearing the helmet mounted projector is followed one field later by the head tracker output. Three fields after the head pointing direction (HPD) data is made available, the CIG completes the processing, and during the fourth field, the generated image is displayed. Since the projector is physically attached to the observer's head, the projector heading (i.e., its projection axis) is identical to the viewer's head pointing direction. In the graph the first curve to the left represents actual head motion, the second curve, the PHT output, and the third curve, the angular heading for which the image being displayed was calculated. The vertical separation between the viewer head motion curve and the CIG image heading curve represents the uncompensated angular image lag, which the viewer observes as an incorrectly positioned image. As previously mentioned, the image lag is equivalent to the angular distance traveled by the head during five TV fields or 83.5 milliseconds.

The second graph in Figure 8 depicts the operation of the rapid head motion compensation system. It can be understood as follows: since the image lag amounts to five fields of head travel, the heading of the helmet mounted projector needs to be shifted back five fields of head travel in order to

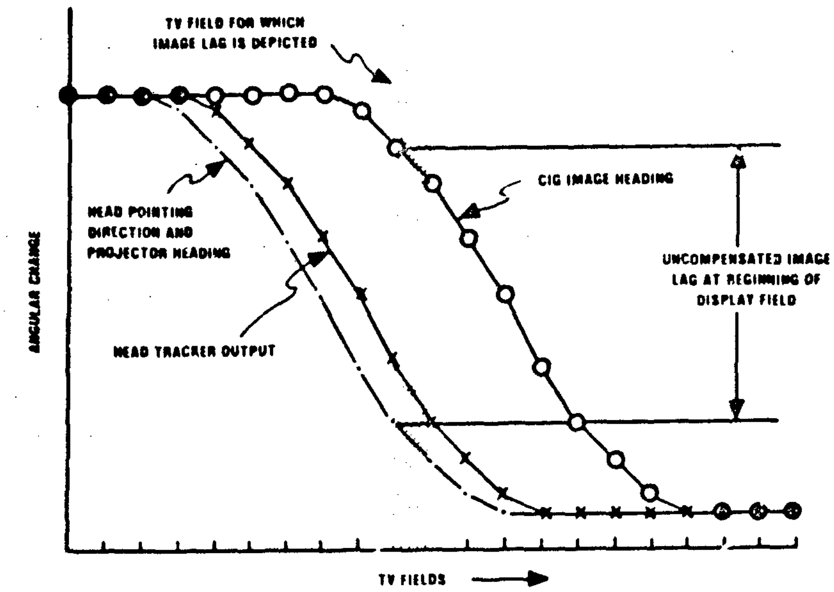


FIGURE 8A

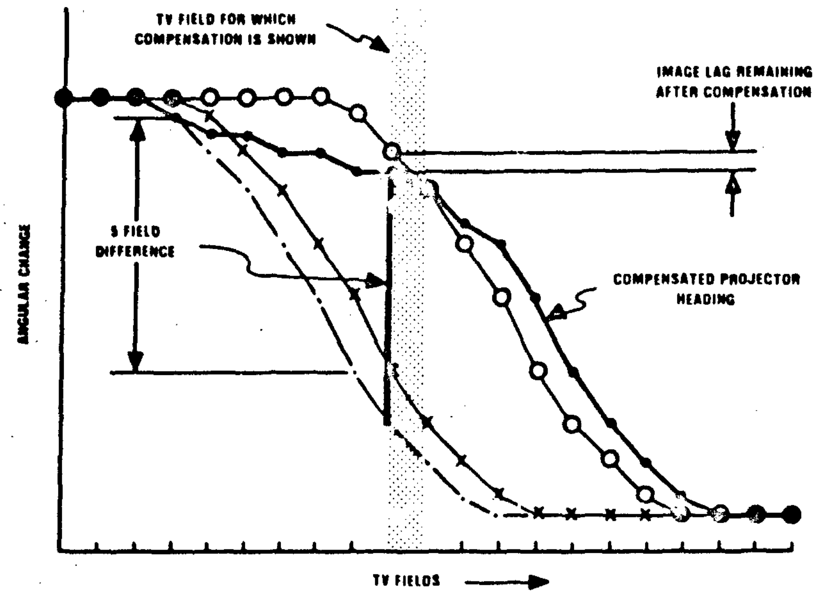


FIGURE 8B

Figure 8. Effects of Lag Compensation.

coincide with the heading of the displayed image. The projector heading is changed by offsetting the position of the horizontal line scan. The offset is performed during the vertical blanking interval just prior to actual display of the image. The most recent head position information available is received just before the occurrence of vertical sync. The difference between the most recent HPD data and the fifth previous piece of HPD data amounts to the angular change in head position over five fields. Essentially then, the projector heading is changed using the most recent five field head position change available. This operation is graphically illustrated by noting that the five field difference "DIFF 5" (see Appendix A, RHMC Software) is added to the actual head position at the beginning of the display field via horizontal raster shifting. This produces a compensated projector heading, where the difference between the compensated heading and the CIG image heading is angular discrepancy still remaining after compensation. Note that although the compensation is not perfect, the remaining image lag is considerably less than the uncompensated image lag, and the image is generally compensated when the viewer's head has completed the motion.

Further information detailing the implementation of both the software and the hardware in Rapid Head Motion Compensation can be found in the Appendices of this report.

SECTION IV

OBSERVATIONS AND CONCLUSIONS

It's clear that neither fiber optic bundle transmits a totally acceptable line scan. The full frame bundle, utilized becaused of its in-house availability, offers many redundant rows of fibers on which a line scan can be focused. Still, finding a row or group of rows which has no broken fibers is impossible. Unlike the full frame bundle, the ribbon bundle provides improved mobility, but at the expense of unevenly spaced fibers, a quantity of borken fibers and poorly polished fiber ends. Despite these contrary observations, a coherent fiber optic ribbon bundle should be available and suitable for future use with development of appropriate manufacturing techniques.

The Acousto Optic Beam Deflector (AOBD) produces an unevenly focused, non-linear horizontal line scan. This is due to the VCO's inability to supply a linear frequency chirp with a power variation of less than ± 2db. Power variation results in a line scan that varies in brightness. Non-linearity in the chirp produces a non-linear line scan that varies in focus. Attempts were made to linearlize the line scan by suitably shaping the ramp signal that served as the input to the VCO. One promising method involves the use of a fast digital to analog converter. The in-house efforts, however, met with little success. At present, the best alternative seems to involve the use of a high speed, rotating scanner mirror system manufactured by Speedring, a division of Schiller Industries, Inc., which is now planned for use in the Visual Display Research Tool.

The display distortion and lack of resolution was judged objectionable by most viewers. Display distortion was far more than the typical viewer would observe on his own home television although exact measurements were not made. Figure 9 shows a test grid as displayed by the HMD system. The distortion occurs both vertically and horizontally, although the horizontal distortion is more extreme. The resolution was determined to be approximately 200 TV line pairs under the most optimal conditions.

The head tracker utilized is acceptable for this particular visual display. Some minor modifications were made which reduce the HPD data filtering. This decreases the settling time for small angular step changes but increases the jitter in the HPD data. Since the resolution of the feasibility model's display is low, the jitter is not directly observable by a subject wearing the helmet. In order to preserve the resolution of the imagery presented by the follow-on VDRT, it has been determined that a head tracker with at least 14-bit accuracy or better is required to keep the jitter at a pixel or sub-pixel level. If the helmet mounted sensor and cockpit mounted emitter are properly placed, the aluminum housing of the projector (a moving metallic mass) does not appear to significantly affect the accuracy of the HPD data. Generally, it is felt that the absolute accuracy of the head tracker is less important than its ability to resolve small angular changes and provide low noise data rapidly.

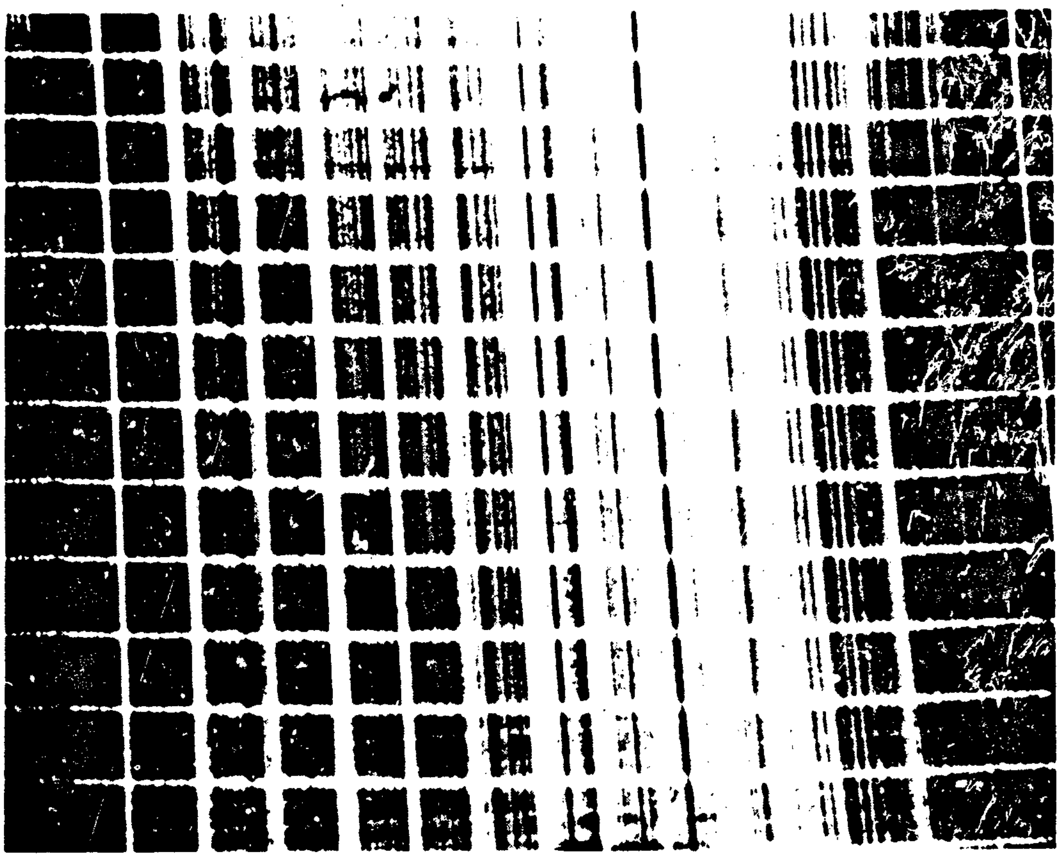


Figure 9. Grid Patterns Displayed by Helmet Mounted Projector.

The overall effect of the RHMC system is an increase in scene stability during head motions of the observer. During the testing, tweaking and evaluation of the feasibility model, many people viewed the display with RHMC both operational and non-operational. With the compensation system functioning, most indicated the image lag was not directly observable; when the compensation system was switched off, all viewers were acutely aware of the swimming effects caused by the lag. Those intimately familiar with the system could cause lag effects simply by exceeding the shifting capability of the RHMC system. Although a cause of concern at first, no compensation was provided for head roll. It seems that most viewers were incapable of achieving roll speeds at which the effects might be observable or, the display was too small to observe them. No roll compensation is planned for the VDRT.

Several major issues remain unresolved. An eye tracker will be required in the VDRT; yet, there is no known method which combines the properties of rapid update and unobtrusive measurement. Raster shifting will produce some display distortion when used in a wide FOV system (such as the VDRT). The distortion correction, if any, that may be required of the CIG remains to be determined. One additional issue concerns data base modeling. In the VDRT, objects within the environmental data base will consistently be making the transition from the low resolution IFOV, where they are modeled in relatively low detail, into the high resolution AOI where they become high detail models. The blend region around the AOI should reduce the problem somewhat, but unfortunately, the change in detail will take place in the motion sensitive peripheral viewing region of the eye. It is not clear at this point how to model objects within a data base to make the transition unobtrusive. Still more investigation and research is needed for answers.

APPENDIX A

RHMC SOFTWARE

The software for RHMC has two functions. One function is to keep a record of past HPD values and then to calculate the required amount of raster shifting for proper image placement. This function is interrelated with the PHT and CIG video timing, with the vertical sync of the CIG video being the master timing signal for the software and PHT. The second function is essentially transparent to the logic flow of the software and concerns the loading of three data buffers for the transfer of HPD data to the CIG.

The software has several tasks in order to accomplish raster shifting. First is the initialization and updating of two tables in RAM for the storage of past and present HPDs. These two tables, one each for vertical and horizontal data, are shown in Figure A1. The most recent (or present) values, W-0, are placed at the top of the tables and moved down to the W-1 position when a new HPD data set is obtained. This downwards movement of an HPD value in the tables continues each time a new data set is obtained (W-1 to W-2, W-2 to W-3, W-3 to W-4, W-4 to W-5) until the data is no longer needed and is discarded. Initialization of the tables is performed by subroutine TABLESET which loads the boresight values (zero degrees) into the two tables. The downward movement of the table values is accomplished via the subroutine FIFO during the time that the PHT is calculating the new HPD values.

The length of the tables determines the number of HPD values to be stored, and at the same time, implies the number of field times delay for which the program will compensate. For a five field delay in PHT to CIG image presentation, the tables must store the five previous HPD samples plus the present sample for a total of six HPD words per table. The error in image placement, for an exact five field delay, is simply the difference between the present sample (W-0) and the W-5 sample. With the present sample always at the top of the table and the fifth previous sample always at the bottom, the error value is found by subtracting the last word in the table from the first word. Below each table there are two reserved bytes of RAM that are used to store the sign of the angular error and the value of the shift word to be sent to the output DACs for shifting the raster.

Figure A1 also shows the reserved RAM areas for a table of input values which are used to determine the length of the HTABLE and VTABLE and to set up needed constants. The values (H or V)INITIAL and (H or V)FINAL are the first and last RAM addresses used to store HPD samples (2 bytes per sample). For five fields delay and the required six sample storage, 12 bytes are needed per table. In the figure, the HINITIAL value is 2020hex and HFINAL is 202Bhex. The (H or V)SOURCE values are used by FIFO to point to the first byte to be moved two addresses downward, with the (H or V)INITIAL values indicating the last byte to be moved. Constants in the Input Table are as follows:

INPUTS

Address	Value	Name
2000	20	HINITIAL
2001	20	
2002	30	VINITIAL
2003	20	
2004	29	HSOURCE
2005	20	
2006	30	VSOURCE
2007	20	
2008	2B	HFINAL
2009	20	
200A	3B	VFINAL
200B	20	
200C	0D	HCONTROL
200D	0D	VCONTROL
200E	A7	HCENTER
200F	A7	VCENTER
2010	00	HZERO
2011	80	
2012	00	VZERO
2013	80	
2014		MASK VALUE
2015	3B	HMAX
2016	3B	VMAX
2017		
2018		
2019		
201A		SCRATCH1
201B		
201C		SCRATCH2
201D		
201E		
201F		

HTABLE

Address	Contents
2020	HW_0
2021	
2022	HW_1
2023	
2024	HW_2
2025	
2026	HW_3
2027	
2028	HW_4
2029	
202A	HW_5
202B	
202C	SIGN
202D	HSHIFT
202E	
202F	
2030	VW_0
2031	
2032	VW_1
2033	
2034	VW_2
2035	
2036	VW_3
2037	
2038	VW_4
2039	
203A	VW_5
203B	
203C	SIGN
203D	VSHIFT
203E	
203F	

Figure A1. NTHPREV Reserved RAM Inputs and Tables.

(H or V)CONTROL	-	provides for the fine adjustment of shift values sent to DACs (see subroutine ADJUST).
(H or V)CENTER	-	centering values for raster to be sent to the DACs.
(H or V)ZERO	-	the boresight (or zero degree value) used to initialize the tables.
MASK	-	value used in setting 8085 mask for interrupt priority.
(H or V)MAX	-	limit the shift values sent to the DACs (must be set less than 3Bhex).

There are also four bytes reserved below the Input Table for temporary storage purposes designated as SCRATCH1 and SCRATCH2.

Once the HTABLE and VTABLE are initialized and an update is received from the PHT, the process of computing the two 8-bit words for controlling the raster placement on the target plane of the projection lens begins. This process is performed by subroutines HSHIFT and VSHIFT for the horizontal and vertical offset values. Referring to the flowchart for HSHIFT in the appendices, the first step is to find the difference, HDIFF, between the present and fifth previous horizontal samples as explained previously. The next step is to use the HDIFF value to calculate the HSHIFT offset value.

The HSHIFT value is dependent on the target plane raster size, the projections lens, and the reference voltage for the DACs. The HSHIFT value for the laser based HMD system is calculated according to the focal length of the lens and the required displacement of the raster to effect an angular shift of the projected image equal to the HDIFF value. Suppose that the HDIFF value represents a 1-degree movement of the viewer's head. This corresponds to a 16-bit value of 00B0hex (or 176decimal) for HDIFF. HDIFF must then be scaled to the proper value which will shift the raster horizontally on the target plane and result in an angular shift of the imagery being projected by 1 degree.

To find the scale factor for the horizontal channel, the 8-bit word required to displace the raster line one quarter of its length was experimentally determined to be 32hex or 50decimal. Knowing the focal length (8 mm.) at the target plane, an offset of 32hex results in a 7.6 degree shift of the projected imagery. This corresponds to a 0.15 degree shift of the image per unit offset increment sent to the horizontal digital to analog converter (HDAC). Therefore, to shift the image by 1 degree, an offset value of approximately 07hex is needed. Hence, a scale factor of 1/26 decimal is needed to scale the HDIFF value of 00B0hex to its proper value of 07hex before being sent to the HDAC. However, due to the limited instruction set of 8085 up, division by 26 is not directly accomplished. To solve this problem, the direction taken was to add a percentage of the HDIFF value to itself (in the form of N*HDIFF/32 or N*3 percent of HDIFF) and then to divide this new adjusted HDIFF, NHDIFF, by 32 (by shifting NHDIFF 5 bits to the right) to effect an approximate division by 26. This adjustment is performed by subroutine ADJUST, which also allows minor adjustment in the RHMC shifting to account for delays which are not integer multiples of field times. After the magnitude of the horizontal offset value is found, the sign of the angular difference is used to determine whether to add or subtract the offset value to or from the raster centering value. This decision determines the shift direction to be either to the right or left depending on the direction of head motion.

The VSHIFT value, however, is not dependent on the projection lens or the raster size. This is due to the fact that the angular shifting of the image in the vertical direction is performed by offsetting the central positioning of the frame scanning mirror, which is located after the projection lens. Here, the 8-bit word required to shift the image in the vertical direction by 4 degrees was experimentally determined to be 16hex (or 22decimal), resulting in a 0.18 degree shift per unit offset sent to the VDAC. These constants indicate that the scale factor for the vertical channel should be 1/29decimal. Once again, the ADJUST subroutine allows for an effective approximate division of VDIFF by 29 and minor adjustment of the shift value magnitude. When the VOFFSET magnitude is calculated, the sign of the angular difference is used to determine whether to add or subtract the VOFFSET magnitude to or from the vertical raster centering value.

The overall effect of the RHMC system was an increase in scene stability during head motions of the observer. Once the system had been incorporated into the HMD, subjective experiments were performed to fine tune the compensation effect by varying the control words for the ADJUST subroutine. These control words were found to be valuable in adjusting for changes in the focal length of the final projection lens, as well as for their intended use of providing a means to compensate for CIG-PHT delays that are integer multiples of a field time.

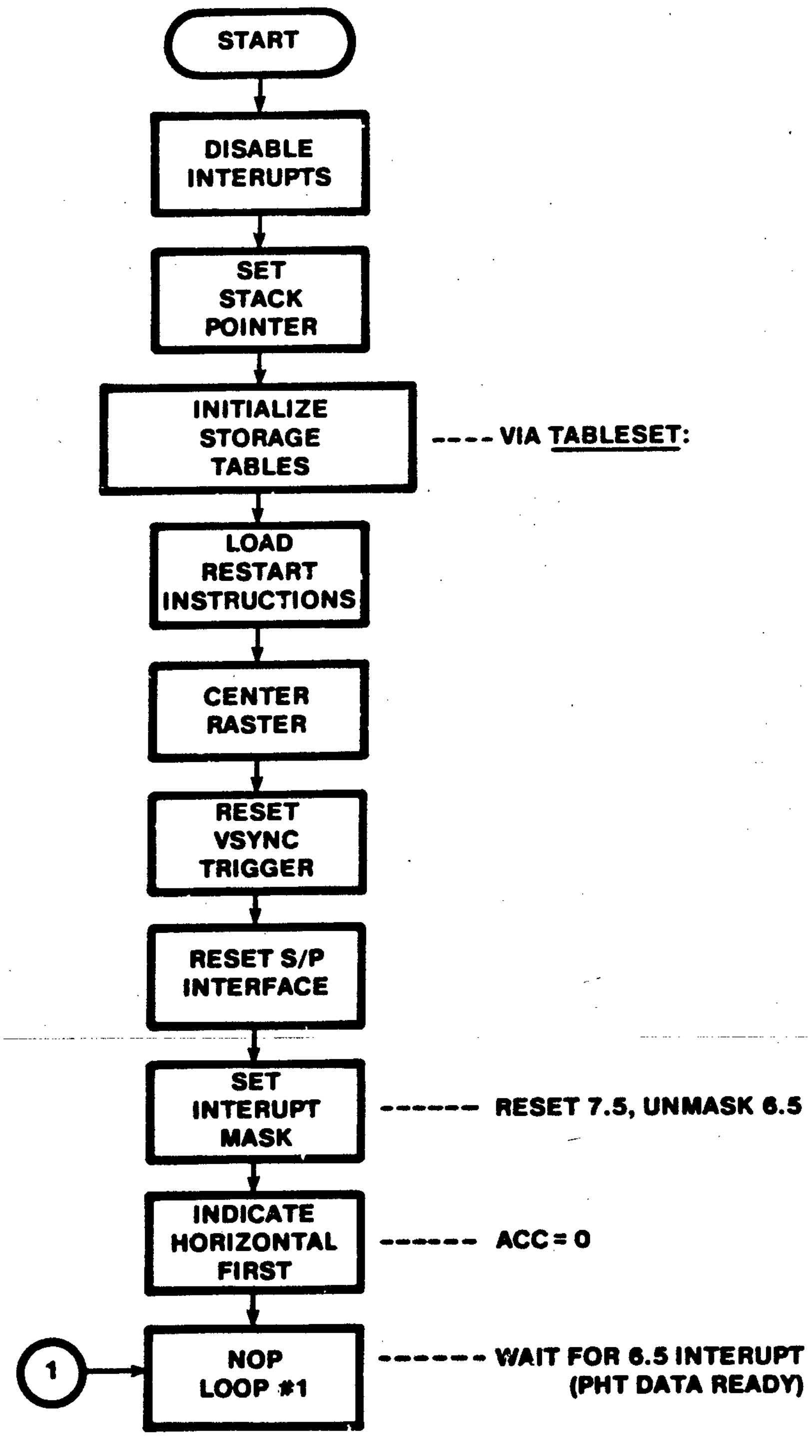
Sometime just before or during the pending vertical sync, the RHMC program finishes calculating the two 8-bit words representing respectively the horizontal and vertical raster shift (HSHIFT and VSHIFT). Then the system enters a loop and waits for the next occurrence of vertical sync (7.5 interrupt); when vertical sync occurs, the program responds by outputting the two 8-bit words to the horizontal and vertical digital to analog converters (HDAC and VDAC). The voltage output of the DACs control the extent of the raster shift required. The output of the HDAC frequency shifts the chirp that drives the acousto optic beam deflector (AOBD), causing an offset of the horizontal line scan. Shifting the helmet mounted mirror scanner with the VDAC raster is done only during the vertical retrace time (i.e., during the vertical sync). By introducing a shift during the time that the video is blanked, the whole raster is shifted as a unit and tearing or separation of the displayed raster is avoided.

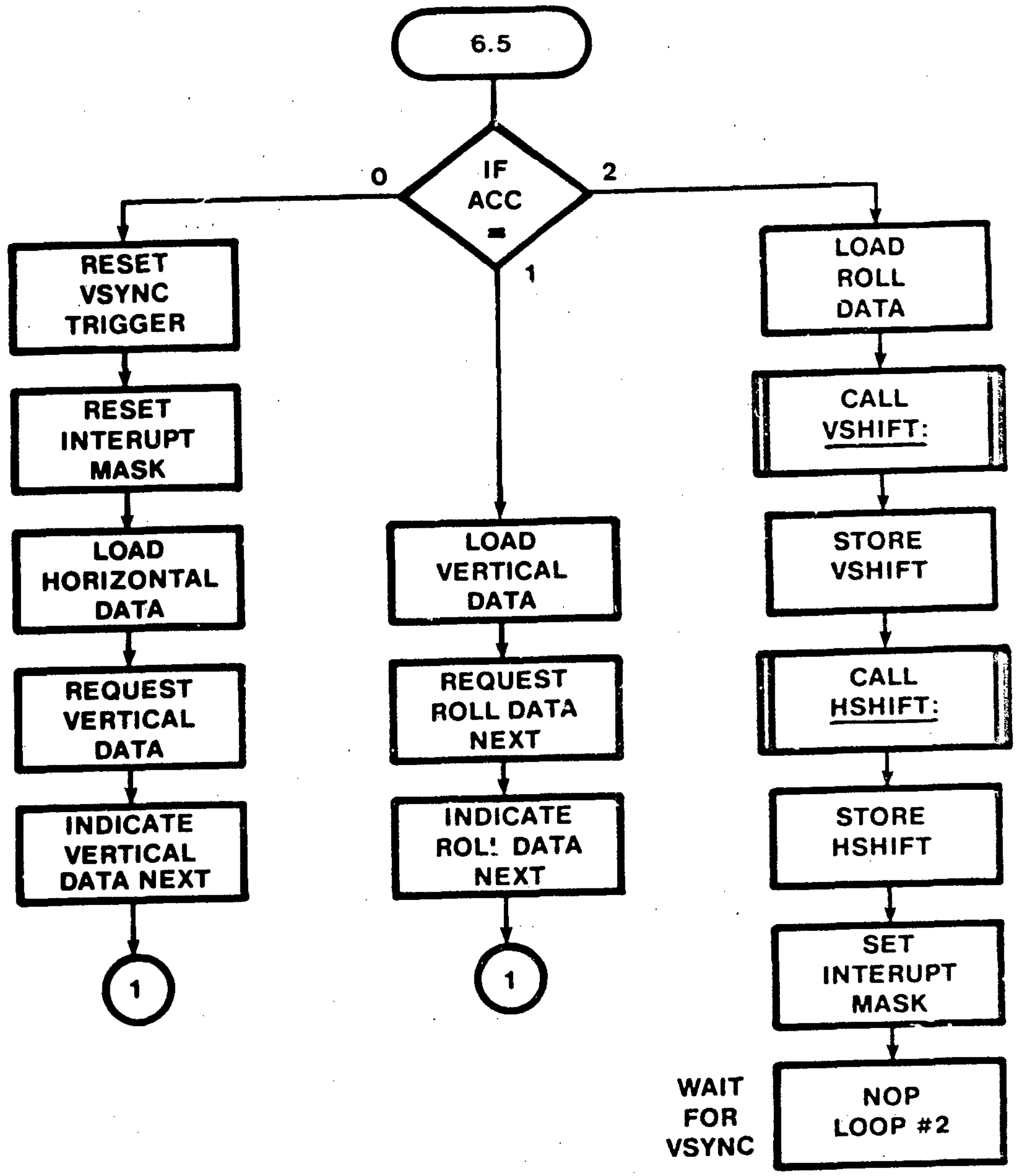
ASM80 F3 LPREV SRC DEBUG MOD85

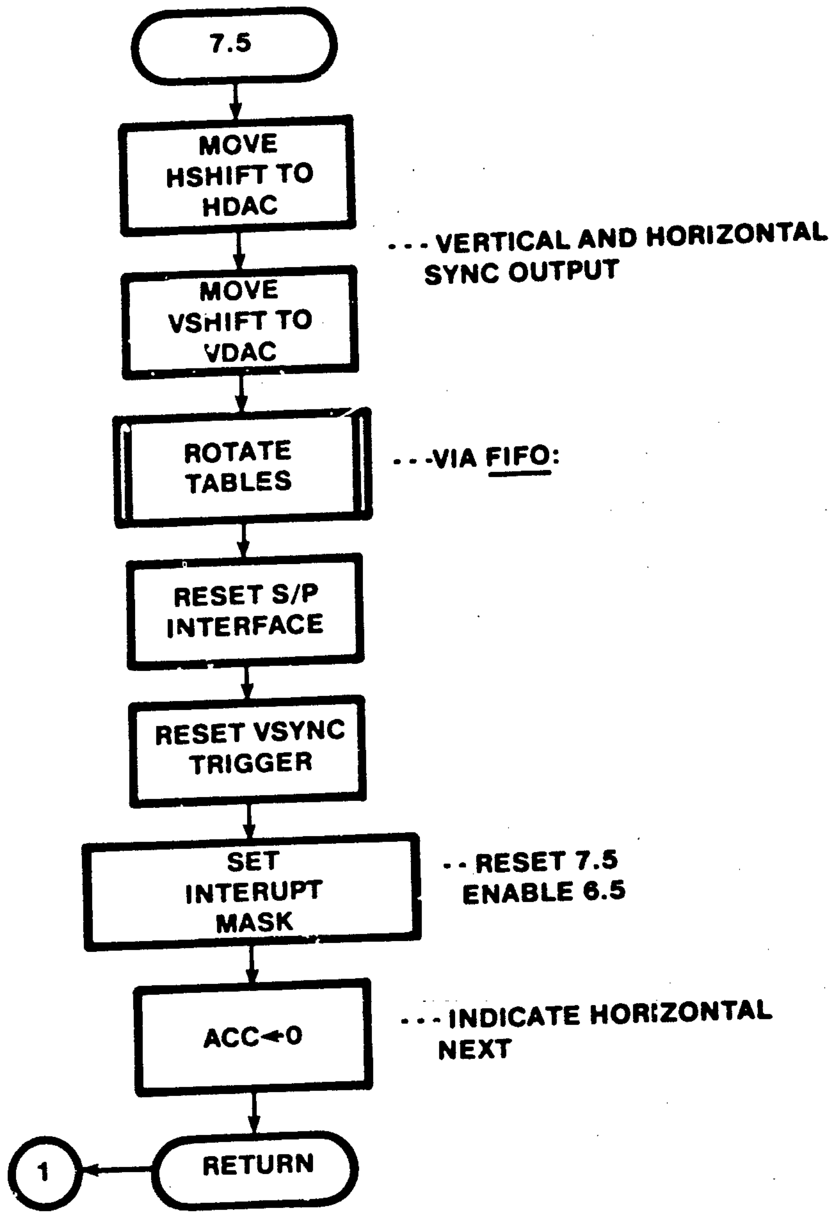
ISIS-II 8080/8085 MACRO ASSEMBLER, V3.0   LPREV

```
LOC  OBJ        LINE        SOURCE STATEMENT

                                NAME    LPREV
                            ;
                            ;
                            ;
                            ;           UPDATED FOR LASER PROJECTOR JULY 2 1981
                            ;
                            ;
                            ;
                            ;
                            ;
                            ;
                            ;                           ******************
                            ;                           *                *
                            ;                           *     LPREV      *
                            ;                           *                *
                            ;                           ******************
                            ;
                            ;
                            ;
                            ;   THIS PROGRAM IS A MODIFICATION OF NTHPREV FOR THE LASER DISPLAY SYSTEM
                            ;
                            ;
                            ;    NTHPRV IS THE MAIN PROGRAM FOR RAPID HEAD MOTION COMPENSATION. THE PROGRAM COMPENSATES
                            ;   FOR CIG DELAY TIME IN THE PHT-CIG--VIEWER LOOP. THE BASIC ALGORITHM USES THE
                            ;   DIFFERENCE IN HEAD AZIMUTH AND ELEVATION FROM THE PRESENT VIDEO FIELD TO THE
                            ;   NTHPREVIOUS FIELD. THIS DIFFERENCE IS USED TO OFFSET THE RASTER IMAGE OPPOSITE
                            ;   THE DIRECTION OF HEADING CHANGES (VERT. AND HORIZ. ONLY)
                            ;
                            ;   THIS OFFSET IS ADJUSTABLE VIA THE EQUATION
                            ;
                            ;               OFFSET = DIFF +- N * (DIFF/16)
                            ;                        ---------------------
                            ;                                32
                            ;
                            ;   WHERE N IS A CONTROL VALUE WITH AN ALLOWED RANGE OF +- 31 FOR EACH INDIVIDUAL OFFSET
                            ;   ( SEE SUBROUTINE ADJUST ).
                            ;
                            ;
                            ;    THE SHIFTING OF THE RASTER IS ACCOMPLISHED BY CHANGING THE VERTICAL AND HORIZONTAL
                            ;   SYNC SIGNALS DURING THE VERTICAL RETRACE TIME. THE AMOUNT OF OFFSET IS LIMITED BY
                            ;   HMAX AND VMAX VALUES WHICH SHOULD BE SET AT A MAXIMUM OF 91 DECIMAL.
                            ;   BEFORE RUNNING THIS PROGRAM BE CERTAIN THAT THE RESERVED RAM LOCATIONS ARE FILLED
                            ;   WITH THE PROPER INFORMATION THAT DEFINE THE STORAGE TABLES, CONTROL VALUES, AND
                            ;   MAXIMUM SHIFT VALUES. THIS MAY BE DONE VIA SUBROUTINES INT4, INT5, OR INT6
                            ;
                            $EJECT
```

NTHPREV


START
DISABLE INTERUPTS
SET STACK POINTER
INITIALIZE STORAGE TABLES
---- VIA TABLESET:
LOAD RESTART INSTRUCTIONS
CENTER RASTER
RESET VSYNC TRIGGER
RESET S/P INTERFACE
SET INTERUPT MASK
------ RESET 7.5, UNMASK 6.5
INDICATE HORIZONTAL FIRST
------ ACC = 0
1
NOP LOOP #1
------ WAIT FOR 6.5 INTERUPT
(PHT DATA READY)


6.5
IF
ACC
=
0
1
2
RESET
VSYNC
TRIGGER
RESET
INTERUPT
MASK
LOAD
HORIZONTAL
DATA
REQUEST
VERTICAL
DATA
INDICATE
VERTICAL
DATA NEXT
1
LOAD
VERTICAL
DATA
REQUEST
ROLL DATA
NEXT
INDICATE
ROLL DATA
NEXT
1
LOAD
ROLL
DATA
CALL
VSHIFT:
STORE
VSHIFT
CALL
HSHIFT:
STORE
HSHIFT
SET
INTERUPT
MASK
WAIT
FOR
VSYNC
NOP
LOOP #2


7.5
MOVE HSHIFT TO HDAC
... VERTICAL AND HORIZONTAL SYNC OUTPUT
MOVE VSHIFT TO VDAC
ROTATE TABLES
... VIA FIFO:
RESET S/P INTERFACE
RESET VSYNC TRIGGER
SET INTERUPT MASK
-- RESET 7.5 ENABLE 6.5
ACC←0
... INDICATE HORIZONTAL NEXT
RETURN
1

ISIS-II 8080/8085 MACRO ASSEMBLER, V3.0   LPREV

```
LOC  OBJ        LINE        SOURCE STATEMENT

                  47 ;
                  48 ;
                  49          EXTRN    TBSUB, DIV32, DIV16, ADJUST, TBADD, MAX, TBLSET, FIFO, PEGOUT
                  50          EXTRN    MESS, STORE1, STK, INPUTS, HINITL, VINITL, HSRC, VSRC, HFINAL, VFINAL
                  51          EXTRN    HCONTR, VCONTR, HCENTR, VCENTR, HZERO, VZERO, HMAX, VMAX, SCRCH1, SCRCH2
                  52          EXTRN    HINPUT, VINPUT, RINPUT, GETELV, RSTSP, VSYNC, HDAC, VDAC, FIRST
                  53          EXTRN    RST658, RST65A, RST75E, RST758
                  54 ;
                  55 $EJECT
```

```
ISIS-II 8080/8085 MACRO ASSEMBLER, V3.0        LPREV

LOC  OBJ          LINE        SOURCE STATEMENT

                    56         CSEG
0000 F3             57 LPREV:  DI                           ;** DISABLE INTERRUPTS **
0001 310000    E    58         LXI      SP,STK              ;SET STACK POINTER
                    59 ;
0004 210000    E    60         LXI      H,FIRST             ;LOAD RESTART 6.5 INSTRUCTIONS
0007 220000    E    61         SHLD     RST658
000A 215400    C    62         LXI      H,MNSEG             ;ADDRESS OF MAIN PROGRAM SEGMENT
000D 220000    E    63         SHLD     RST65A
                    64 ;
0010 210000    E    65         LXI      H,FIRST             ;LOAD RESTART 7.5 INSTRUCTIONS
0013 220000    E    66         SHLD     RST75E
0016 21C200    C    67         LXI      H,OUTPUT            ;ADDRESS OF SYNC OUTPUT SEGMENT
0019 220000    E    68         SHLD     RST750
                    69 ;
001C 2A0000    E    70         LHLD     HZERO
001F EB             71         XCHG
0020 3A0000    E    72         LDA      HFINAL
0023 2A0000    E    73         LHLD     HINITL
0026 CD0000    E    74         CALL     TBLSET              ;INITIALIZE HTABLE WITH HZERO
0029 2A0000    E    75         LHLD     VZERO
002C EB             76         XCHG
002D 3A0000    E    77         LDA      VFINAL
0030 2A0000    E    78         LHLD     VINITL
0033 CD0000    E    79         CALL     TBLSET              ;INITIALIZE VTABLE WITH VZERO
                    80 ;
0036 3A0000    E    81         LDA      HCENTR
0039 320000    E    82         STA      HDAC                ;SEND CENTER VALUE TO HDAC
003C 3A0000    E    83         LDA      VCENTR
003F 320000    E    84         STA      VDAC                ;SEND CENTER VALUE TO VDAC
                    85 ;
0042 320000    E    86         STA      RSTSP               ;RESET SERIAL TO PARALLEL BOARD
0045 320000    E    87         STA      VSYNC               ;AND VSYNC TRIGGER
0048 3E1D           88         MVI      A,1DH
004A 30             89         SIM                          ;SET INTERUPT MASK
                    90 ;                                   RESET 7.5 ,UNMASK 6.5
                    91 ;
004B 3E00           92         MVI      A,00H               ;INDICATE HORIZONTAL FIRST (ACC=0)
004D FB             93         EI
004E 00             94 LOOP1:  NOP                          ;—— LOOP #1 —— WAIT FOR DATA READY
004F 00             95         NOP
0050 00             96         NOP                          ;WAIT FOR 6.5 INTERUPT
0051 C34E00    C    97         JMP      LOOP1               ;THEN GO TO MAIN SEGMENT
                    98 ;
                    99 MNSEG:          ;****** MAIN SEGMENT ******
0054 FE01          100         CPI      01H                 ;IF ACC = 0 , HORIZONTAL DATA
0056 CA7200    C   101         JZ       VERT                ;IF ACC = 1 , VERTICAL DATA
0059 FE02          102         CPI      02H                 ;CHECK FOR ROLL DATA
005B CA[illegible] C   103         JZ       ROLL                ;IF ACC = 2 , ROLL DATA
                   104 $EJECT
```

ISIS-II 8080/8085 MACRO ASSEMBLER, V3 0   LPREV

```
LOC  OBJ          LINE        SOURCE STATEMENT

                   105 ;
                   106 ;
                   107 RSET:                                ;SET UP TO GRAB NEXT VSYNC
                   108 ;
005E 320000   E    109         STA     VSYNC               ;RESET VSYNC TRIGGER
                   110 ;
0061 3E1D          111         MVI     A,1DH
0063 30            112         SIM                         ;RESET 7.5,ENABLE 6.5
                   113 ;
0064 2A0000   E    114 HORIZ:  LHLD    HINPUT
0067 EB            115         XCHG                        ;(D,E) - DATA FROM PORT
0068 2A0000   E    116         LHLD    HINITL              ;(H,L) - HINITIAL ADDRESS
006B 73            117         MOV     M,E
006C 23            118         INX     H
006D 7A            119         MOV     A,D                 ;ACC GETS HI BYTE OF HINPUT
006E 17            120         RAL
006F 3F            121         CMC                         ;COMPLIMENT MSB OF HINPUT
0070 1F            122         RAR
0071 77            123         MOV     M,A                 ;STORE HI BYTE OF HINPUT IN HTABLE
0072 320000   E    124         STA     GETELV              ;SEND GET ELEVATION SIGNAL
0075 3E01          125         MVI     A,01H               ;INDICATE VERTICAL DATA NEXT
0077 FB            126         EI                          ;ENABLE INTERUPTS
0078 C9            127         RET                         ;AND RETURN TO LOOP1
                   128 ;
0079 2A0000   E    129 VERT:   LHLD    VINPUT              ;VERTICAL INPUT SEGMENT
007C EB            130         XCHG                        ;(D,E) - VERTICAL DATA
007D 2A0000   E    131         LHLD    VINITL              ;(H,L) - VINITIAL ADDRESS
0080 73            132         MOV     M,E                 ;STORE LO BYTE OF VINPUT
0081 23            133         INX     H                   ;POINT TO NEXT LOCATION
0082 7A            134         MOV     A,D
0083 17            135         RAL
0084 3F            136         CMC                         ;COMPLIMENT MSB OF VINPUT
0085 1F            137         RAR
0086 77            138         MOV     M,A                 ;STORE HI BYTE IN VTABLE
0087 3E02          139         MVI     A,02H               ;INDICATE ROLL DATA NEXT
0089 320000   E    140         STA     GETELV              ;REQUEST ROLL DATA FROM PHT
008C FB            141         EI                          ;ENABLE INTERUPTS
008D C9            142         RET                         ;RETURN TO LOOP #1
                   143 ;
008E 2A0000   E    144 ROLL:   LHLD    RINPUT              ;ROLL INPUT SECTION
0091 EB            145         XCHG                        ;(D,E) GETS ROLL DATA
0092 211E20        146         LXI     H,201EH             ;(H,L) CONTAINS STORAGE ADDRESS
0095 73            147         MOV     M,E                 ;STORE LO-BYTE OF ROLL
0096 23            148         INX     H                   ;POINT TO MEM. 201F
0097 7A            149         MOV     A,D
0098 17            150         RAL
0099 3F            151         CMC                         ;COMPLIMENT MSB OF RINPUT
009A 1F            152         RAR
009B 77            153         MOV     M,A                 ;STORE HI-BYTE OF RINPUT
                   154 $EJECT
```

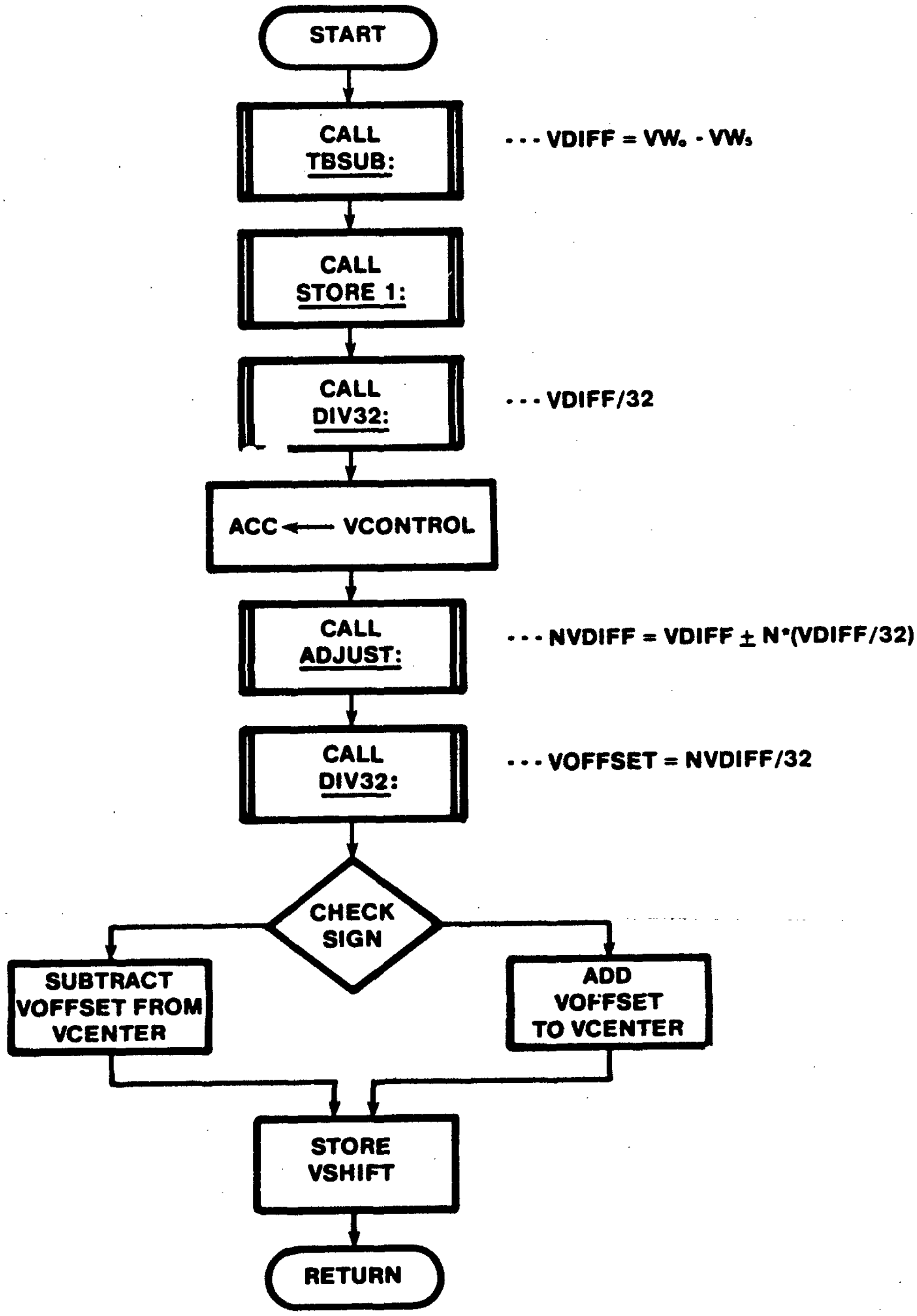
```
ISIS-II 8080/8085 MACRO ASSEMBLER, V3.0        LPREV

 LOC  OBJ          LINE        SOURCE STATEMENT

                    155 ;  CALCULATE SHIFT VALUES (VERTICAL AND HORIZONTAL ONLY)
                    156 ;
 009C 2A0000    E   157          LHLD    VINITL
 009F EB            158          XCHG                              ;(D,E) POINTS TO VINITIAL ADDRESS
 00A0 2A0000    E   159          LHLD    VFINAL                    ;(H,L) POINTS TO V WORD FINAL
 00A3 2B            160          DCX     H
 00A4 CDF700    C   161          CALL    VSHIFT                    ;CALCULATE VSHIFT VALUE
 00A7 F5            162          PUSH    PSW                       ;SAVE VSHIFT IN STK
                    163 ;
 00A8 2A0000    E   164          LHLD    HINITL
 00AB EB            165          XCHG                              ;(D,E) - HINITIAL ADDRESS
 00AC 2A0000    E   166          LHLD    HFINAL                    ;(H,L) - H WORD FINAL ADDRESS
 00AF 2B            167          DCX     H
 00B0 CD2701    C   168          CALL    HSHIFT                    ;CALCULATE HSHIFT VALUE
 00B3 F5            169          PUSH    PSW                       ;HSHIFT TO STK
                    170 ;
 00B4 3E0B          171          MVI     A,0BH                     ;
 00B6 30            172          SIM                               ;ENABLE 7.5 INTERUPT (VSYNC)
                    173 ;
 00B7 F1            174          POP     PSW                       ;ACC CONTAINS HSHIFT
 00B8 FB            175          EI                                ;ENABLE INTERUPTS
                    176 ;
 00B9 00            177 LOOP2:   NOP                               ;---- LOOP #2 -
 00BA 320500        178          STA     0005H                     ;INDICATE READY FOR OUTPUT
 00BD 00            179          NOP                               ; WAIT FOR VERTICAL SYNC
 00BE 00            180          NOP                               ;THEN GO TO OUTPUT SEGMENT
 00BF C3B900    C   181          JMP     LOOP2
                    182 ;
                    183 OUTPUT:                                    ;OUTPUT SEGMENT FOR SYNC VALUES
                    184 ;
 00C2 E1            185          POP     H                         ;REMOVE 7.5 RETURN ADDRESS
 00C3 320000    E   186          STA     HDAC                      ;HSHIFT MOVED TO HDAC
                    187 ;
 00C6 F1            188          POP     PSW                       ;ACC CONTAINS VSHIFT
 00C7 320000    E   189          STA     VDAC                      ;VSHIFT MOVED TO VDAC
                    190 $EJECT
```

ISIS-II 8080/8085 MACRO ASSEMBLER, V3 0   LPREV

```
LOC  OBJ          LINE        SOURCE STATEMENT

                   191 ROTATE                           ;SET UP FOR NEXT CYCLE
00CA 3A0000   E    192         LDA     HINITL
00CD 47            193         MOV     B,A              ;B GETS HINITIAL ADDRESS (LO)
00CE 2A0000   E    194         LHLD    HSRC
00D1 EB            195         XCHG                     ;(D,E) GETS HSOURCE ADDRESS
00D2 2A0000   E    196         LHLD    HFINAL           ;(H,L) GETS HFINAL ADDRESS
00D5 CD0000   E    197         CALL    FIFO             ;ROTATE HTABLE
                   198 ;
00D8 3A0000   E    199         LDA     VINITL
00DB 47            200         MOV     B,A              ;B GETS VINITIAL ADDRESS (LO)
00DC 2A0000   E    201         LHLD    VSRC
00DF EB            202         XCHG                     ;(D,E) GETS VSOURCE ADDRESS
00E0 2A0000   E    203         LHLD    VFINAL           ;(H,L) GETS VFINAL ADDRESS
00E3 CD0000   E    204         CALL    FIFO             ;ROTATE VTABLE
                   205 ;
                   206 ;
00E6 320000   E    207         STA     RSTSP            ;RESET SERIAL TO PARALLEL INTERFACE
                   208 ;
00E9 3E0D          209         MVI     A,0DH
00EB 30            210         SIM                      ;ENABLE 6.5 INTERRUPT
00EC 00            211         NOP
00ED 00            212         NOP
00EE 00            213         NOP
00EF 00            214         NOP
00F0 00            215         NOP
00F1 00            216         NOP
00F2 00            217         NOP
00F3 3E00          218         MVI     A,00H            ;INDICATE HORIZONTAL NEXT
                   219 ;
00F5 FB            220         EI                       ;ENABLE INTERUPTS
00F6 C9            221         RET                      ;RETURN TO LOOP1 VIA 6.5 RETURN
                   222 ;
                   223 $TITLE (' VSHIFT ')
                   224 $EJECT
```

```
ISIS-II 8080/8085 MACRO ASSEMBLER, V3.0        LPREV
VSHIFT

 LOC  OBJ        LINE        SOURCE STATEMENT

                  ;
                  ;
                  ;
                  ;              ****************
                  ;              *              *
                  ;              *    VSHIFT    *
                  ;              *              *
                  ;              ****************
                  ;
                  ;      MODIFIED FOR LASER PROJECTOR JULY 2 1981
                  ;
                  ;      VSHIFT IS USED TO CALCULATE THE VERTICAL SHIFT VALUE TO BE SENT TO THE VERTICAL DAC
                  ;
                  ;              VSHIFT  = VCENTER - VOFFSET
                  ;
                  ;              VOFFSET = VDIFF +- N * (VDIFF/16)
                  ;                        -----------------------
                  ;                                  32
                  ;
                  ;
                  ;      VSHIFT USES SUBROUTINES : TBSUB,STORE1,DIV32,DIV16,ADJUST,MAX.
                  ;
                  ;
                  ;INPUTS:
                  ;      (D,E) CONTAINS THE ADDRESSS OF V WORD 0;
                  ;      (H,L) CONTAINS THE ADDRESS OF V WORD FINAL
                  ;      BOTH WORDS ARE TWO BYTE
                  ;
                  ;      VCENTER,VMAX, AND VCONTROL MUST BE IN THEIR PROPER LOCATION IN RAM
                  ;
                  ;OUTPUTS:
                  ;      NVDIFF AT SCRCH1 ( VDIFF +- VCONTROL*VDIFF/16 )
                  ;      HOFFSET AT SCRCH2 ( NVDIFF/32 )
                  ;      THE SIGN OF NVDIFF,VOFFSET IS STORED AT (H,L) + 2
                  ;      VSHIFT IS IN THE ACC. AND AT (H,L) + 3
                  ;
                  $EJECT
```

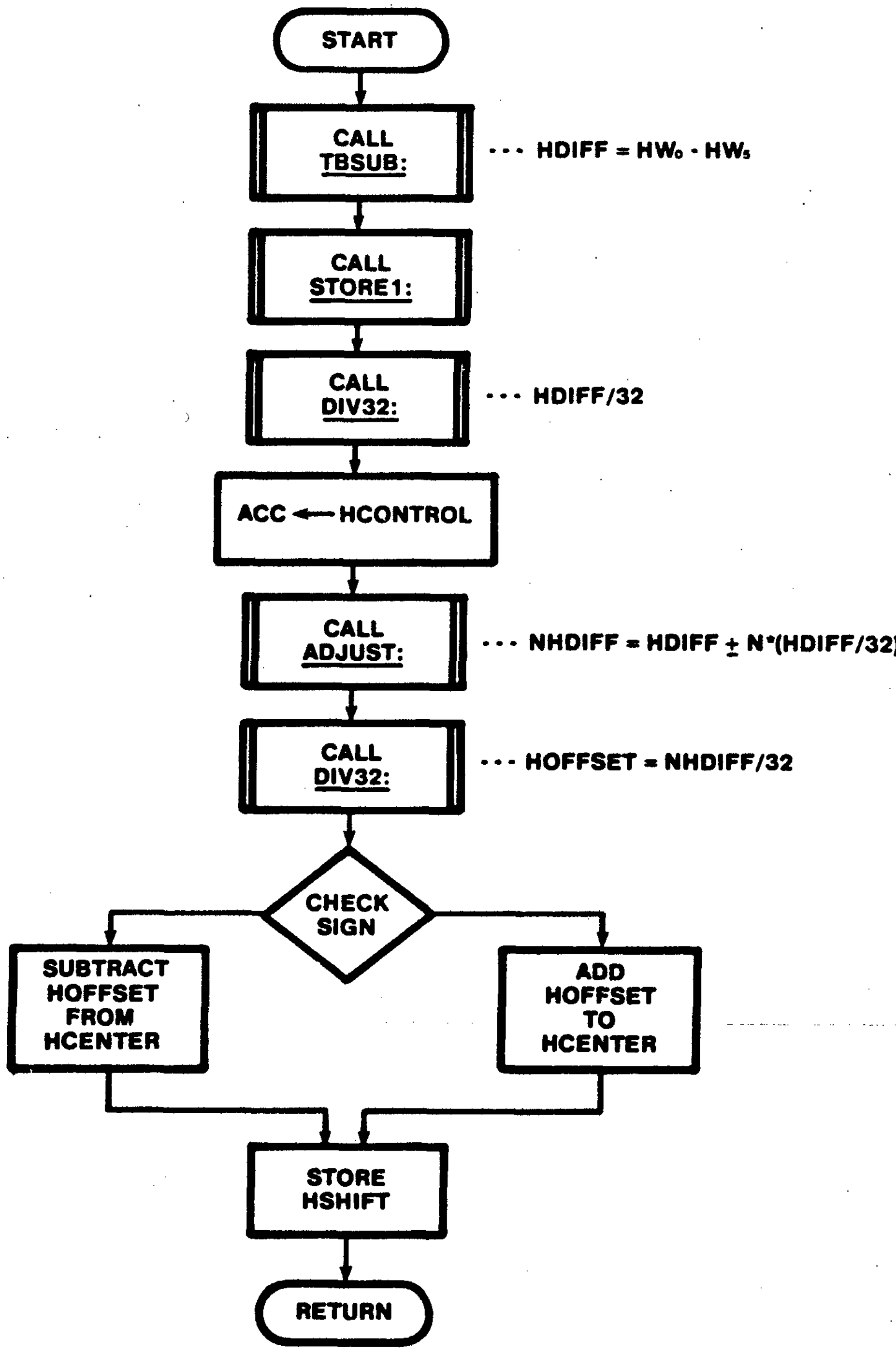
SUBROUTINE VSHIFT



```
ISIS-II 8080/8085 MACRO ASSEMBLER, V3.0        LPREV
VSHIFT

 LOC  OBJ         LINE        SOURCE STATEMENT

                   262 ;
                   263 ;
                   264          CSEG
                   265 VSHIFT:                            ;SAVE (H,L)-V WORD FINAL ADDRESS
 00F7 E5           266          PUSH    H                 ;FIND VDIFF
 00F8 CD0000   E   267          CALL    TBSUB             ;STORE VDIFF AT SCRATCH1
 00FB CD0000   E   268          CALL    STORE1            ;VDIFF/16
 00FE CD0000   E   269          CALL    DIV16
                   270 ;                                  ;ACC GETS VCONTROL
 0101 3A0000   E   271          LDA     VCONTR            ;NVDIFF=VDIFF +- N*(VDIFF/16)
 0104 CD0000   E   272          CALL    ADJUST
                   273 ;                                  ;VOFFSET = NVDIFF/32
 0107 CD0000   E   274          CALL    DIV32
                   275 ;                                  ;ACC GETS MAXIMUM OFFSET
 010A 3A0000   E   276          LDA     VMAX              ;CHECK FOR MAXIMUM SHIFT VALUE
 010D CD0000   E   277          CALL    MAX
                   278 ;
 0110 3A0000   E   279          LDA     VCENTR            ;C GETS VCENTER VALUE
 0113 4F           280          MOV     C,A               ;VWORD FINAL ADDRESS OFF STK
 0114 E1           281          POP     H
 0115 23           282          INX     H                 ;(H,L) POINTS TO SIGN ADDRESS
 0116 23           283          INX     H                 ;ACC GETS SIGN(0-POS ,1-NEG )
 0117 7E           284          MOV     A,M               ;COMPARE SIGN WITH ZERO
 0118 FE00         285          CPI     00H               ;IF SIGN IS POSITIVE SUBTRACT
 011A CA2201   C   286          JZ      MINUS             VOFFSET FROM VCENTER
                   287 ;
                   288 ;
                   289 ;IF SIGN IS NOT ZERO ADD (PLUS,MINUS,AND FINISH ARE USED BY VSHIFT AND HSHIFT)
                   290 ;
                   291 PLUS:                              ;ACC GETS CENTER VALUE
 011D 79           292          MOV     A,C               ;ADD OFFSET TO CENTER
 011E 80           293          ADD     B                 ;FINISH UP SUBROUTINE
 011F C32401   C   294          JMP     FINISH
                   295 ;
                   296 MINUS:                             ;ACC GETS CENTER VALUE
 0122 79           297          MOV     A,C               ;SUBTRACT OFFSET FROM CENTER
 0123 90           298          SUB     B
                   299 ;
                   300 FINISH:                            ;POINT PAST SIGN OF DIFF
 0124 23           301          INX     H                 ;STORE SHIFT VALUE
 0125 77           302          MOV     M,A
                   303 ;                                  ;RETURN TO CALLING PROGRAM
 0126 C9           304          RET
                   305 ;
                   306 ;
                   307 $TITLE (' HSHIFT ')
                   308 $EJECT
```

```
ISIS-II 8080/8085 MACRO ASSEMBLER, V3.0        LPREV
HSHIFT

LOC  OBJ        LINE        SOURCE STATEMENT

            ;
            ;
            ;
            ;
            ;               *****************
            ;               *               *
            ;               *    HSHIFT     *
            ;               *               *
            ;               *****************
            ;
            ;       MODIFIED FOR LASER PROJECTOR JULY 2 1981
            ;
            ;
            ;       HSHIFT IS USED TO CALCULATE THE HORIZONTAL SHIFT VALUE TO BE SENT TO THE HDAC
            ;
            ;               HSHIFT  = HCENTER - HOFFSET
            ;
            ;               HOFFSET = HDIFF +- N * (HDIFF/16)
            ;                         ----------------------
            ;                                   32
            ;
            ;
            ;       HSHIFT USES SUBROUTINES: TBSUB,DIV32,DIV16,STORE1,ADJUST,MAX,PLUS,MINUS,FINISH
            ;
            ;INPUTS:
            ;       (D,E)- CONTAINS THE ADDRESS OF H WORD 0
            ;       (H,L)- CONTAINS THE ADDRESS OF H WORD FINAL
            ;        BOTH WORDS ARE 2-BYTE
            ;
            ;       HCENTER,HMAX, AND HCONTROL MUST BE IN THEIR PROPER LOCATION IN RAM
            ;
            ;OUTPUTS:
            ;       NHDIFF AT SCRCH1 (HDIFF +- HCONTROL*HDIFF/16)
            ;       HOFFSET AT SCRCH2 ( NHDIFF/32 )
            ;       THE SIGN OF HOFFSET,NHDIFF IS STORED AT (H,L) + 2
            ;       HSHIFT IS IN THE ACCUMULATOR AND AT (H,L) + 3
            ;
            $EJECT
```

SUBROUTINE HSHIFT



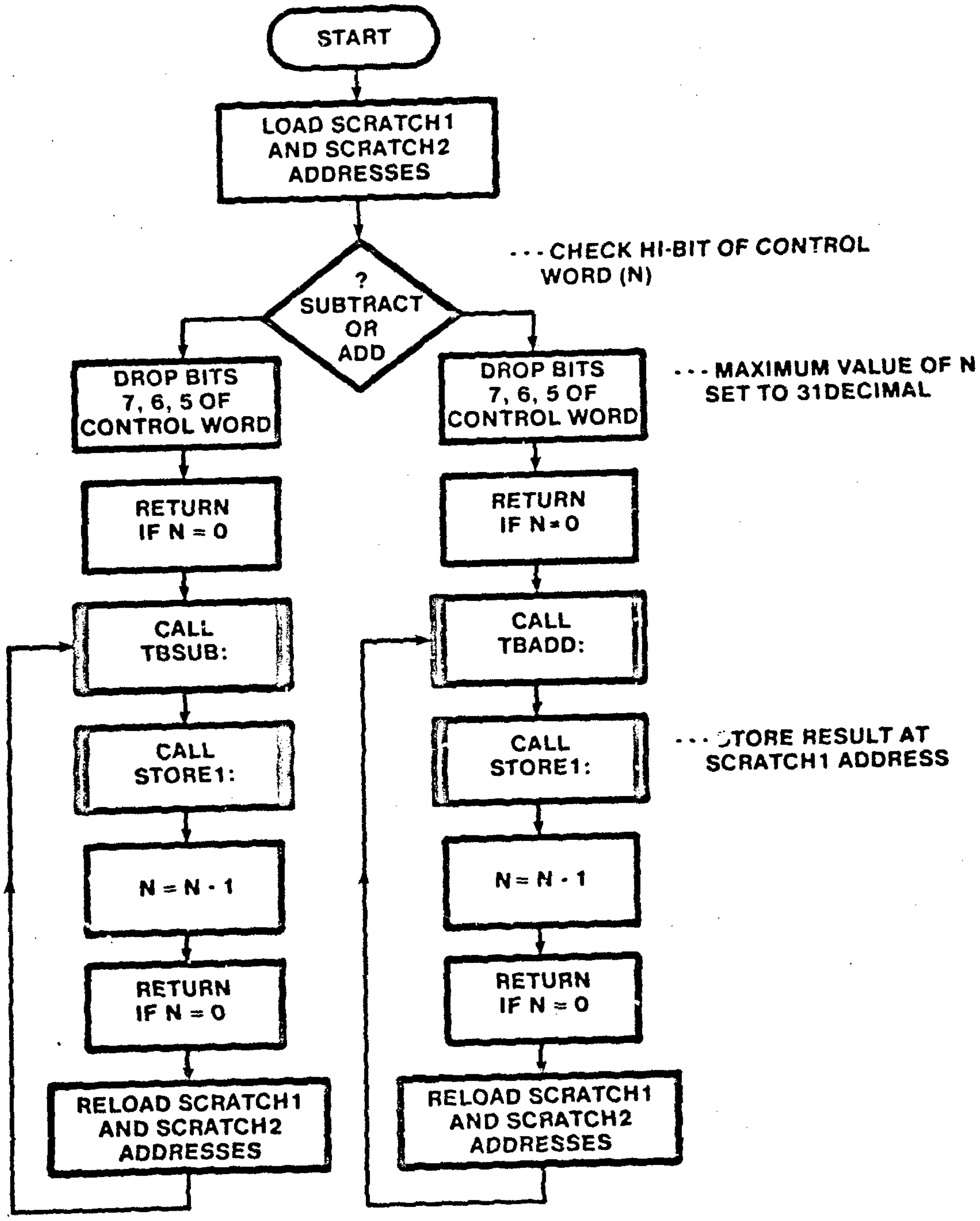
```
ISIS-II 8080/8085 MACRO ASSEMBLER, V3.0          LPREV
HSHIFT

 LOC  OBJ        LINE        SOURCE STATEMENT

                  347 ;
                  348 ;
                  349         CSEG
                  350 HSHIFT:
0127 E5           351         PUSH    H                        ;(H,L) SAVED IN STK
0128 CD0000   E   352         CALL    TBSUB                    ;CALCULATE HDIFF
012B CD0000   E   353         CALL    STORE1                   ;STORE HDIFF AT SCRATCH1
                  354 ;
012E CD0000   E   355         CALL    DIV16                    ;HDIFF/16
                  356 ;
0131 3A0000   E   357         LDA     HCONTR                   ;ACC GETS HCONTROL VALUE
0134 CD0000   E   358         CALL    ADJUST                   ;NHDIFF=HDIFF+-N*(HDIFF/16)
                  359 ;
0137 CD0000   E   360         CALL    DIV32                    ;HOFFSET = NHDIFF/32
                  361 ;
013A 3A0000   E   362         LDA     HMAX                     ;ACC GETS MAXIMUM H SHIFT VALUE
013D CD0000   E   363         CALL    MAX                      ;DETERMINE IF MAX IS REACHED
                  364 ;                                        LEAVE HOFFSET IN B REGISTER
0140 3A0000   E   365         LDA     HCENTR
0143 4F           366         MOV     C,A                      ;C GETS H CENTER VALUE
0144 E1           367         POP     H                        ;H WORD FINAL ADDRESS OFF STK
0145 23           368         INX     H
0146 23           369         INX     H                        ;(H,L) POINTS TO H SIGN LOCATION
0147 7E           370         MOV     A,M                      ;ACC GETS SIGN VALUE (0-POS,1-NEG)
0148 FE00         371         CPI     00H                      ;COMPARE SIGN WITH ZERO
014A CA2201   C   372         JZ      MINUS                    ;IF SIGN IS POSITIVE SUBTRACT
                  373 ;                                        VIA MINUS THEN FINISH SUBROUTINE
                  374 ;
                  375 ;       IF SIGN IS POSITIVE ADD HCENTER TO HOFFSET
                  376 ;
014D C31D01   C   377         JMP     PLUS                     ;ADD THEN FINISH SUBROUTINE
                  378 ;
                  379 $EJECT
```

```
ISIS-II 8080/8085 MACRO ASSEMBLER, V3.0        LPREV
HSHIFT

 LOC  OBJ        LINE        SOURCE STATEMENT

                  380         END

PUBLIC SYMBOLS

EXTERNAL SYMBOLS
ADJUST E 0000   DIV16  E 0000   DIV32  E 0000   FIFO   E 0000   FIRST  E 0000   GETELY E 0000   HCENTR E 0000
HCONTR E 0000   HDAC   E 0000   HFINAL E 0000   HINITL E 0000   HINPUT E 0000   HMAX   E 0000   HSRC   E 0000
HZERO  E 0000   INPUTS E 0000   MAX    E 0000   MESS   E 0000   REGOUT E 0000   RINPUT E 0000   RST65B E 0000
RST65A E 0000   RST750 E 0000   RST75E E 0000   RSTSP  E 0000   SCRCH1 E 0000   SCRCH2 E 0000   STK    E 0000
STORE1 E 0000   TBADD  E 0000   TBLSET E 0000   TBSUB  E 0000   VCENTR E 0000   VCONTR E 0000   VDAC   E 0000
VFINAL E 0000   VINITL E 0000   VINPUT E 0000   VMAX   E 0000   VSRC   E 0000   VSYNC  E 0000   VZERO  E 0000

USER SYMBOLS
ADJUST E 0000   DIV16  E 0000   DIV32  E 0000   FIFO   E 0000   FINISH C 0124   FIRST  E 0000   GETELY E 0000
HCENTR E 0000   HCONTR E 0000   HDAC   E 0000   HFINAL E 0000   HINITL E 0000   HINPUT E 0000   HMAX   E 0000
HORIZ  C 0064   HSHIFT C 0127   HSRC   E 0000   HZERO  E 0000   INPUTS E 0000   LOOP1  C 004E   LOOP2  C 0059
LPREV  C 0000   MAX    E 0000   MESS   E 0000   MINUS  C 0122   MNSEG  C 0054   OUTPUT C 00C2   PLUS   C 011D
REGOUT E 0000   RINPUT E 0000   ROLL   C 008E   ROTATE C 00CA   RSET   C 005E   RST65B E 0000   RST65A E 0000
RST750 E 0000   RST75E E 0000   RSTSP  E 0000   SCRCH1 E 0000   SCRCH2 E 0000   STK    E 0000   STORE1 E 0000
TBADD  E 0000   TBLSET E 0000   TBSUB  E 0000   VCENTR E 0000   VCONTR E 0000   VDAC   E 0000   VERT   C 0079
VFINAL E 0000   VINITL E 0000   VINPUT E 0000   VMAX   E 0000   VSHIFT C 00F7   VSRC   E 0000   VSYNC  E 0000
VZERO  E 0000

ASSEMBLY COMPLETE,   NO ERRORS
```

ISIS-II 8080/8085 MACRO ASSEMBLER, V3 0   SUBS
ADJUST

```
 LOC  OBJ        LINE       SOURCE STATEMENT

                      ;
                      ;       ****************
                      ;       *              *
                      ;       *    ADJUST    *
                      ;       *              *
                      ;       ****************
                      ;
                      ;
                      ;       THIS SUBROUTINE EVALUATES THE MATHEMATICAL EXPPESSION
                      ;
                      ;                    Z = X + ( N * Y )
                      ;
                      ;       WHERE X AND Y ARE TWO BYTE WORDS STORED AT RAM LOCATIONS SCRATCH1 AND
                      ;       SCRATCH2, RESPECTIVLY  N IS A VARIABLE WHICH IS PASSED TO THE
                      ;       SUBROUTINE IN THE ACCUMULATOR ; N HAS AN ALLOWABLE RANGE OF +- 31
                      ;       WITH THE SIGN INDICATED BY THE MSB (#7) OF THE ACC. SET TO 0 FOR
                      ;       POSITIVE OR 1 FOR NEGATIVE.
                      ;
                      ;       THE RESULT Z IS STORED AT THE ORIGINAL LOCATION OF X (SCRATCH 1)
                      ;
                      ;
                      ;INPUTS:
                      ;       ACC CONTAINS THE VARIABLE WORD N
                      ;         MSB  _ X X _ _ _ _ _  LSB  - N
                      ;              7 6 5 4 3 2 1 0 BIT #
                      ;              S    <--RANGE--> = 31
                      ;              I
                      ;              G
                      ;              N   [ IF BIT#7 = 0, N IS POSITIVE]
                      ;                  [ IF BIT#7 = 1, N IS NEGATIVE]
                      ;              ** BITS 6 AND 5 ARE NOT USED ( AND VALUE 1FHEX DROPS THEM )
                      ;
                      ;       X IS CONTAINED IN RAM LOCATIONS SCRATCH1,SCRATCH1 + 1
                      ;
                      ;       Y IS CONTAINED IN RAM LOCATIONS SRCATCH2,SCRATCH2 + 1
                      ;
                      ;
                      ;OUTPUT:
                      ;       Z IS CONTAINED IN RAM LOCATIONS: SCRATCH1 (LO) AND SCRATCH1 + 1 (HI)
                      ;
                      $EJECT
```

ADJUST

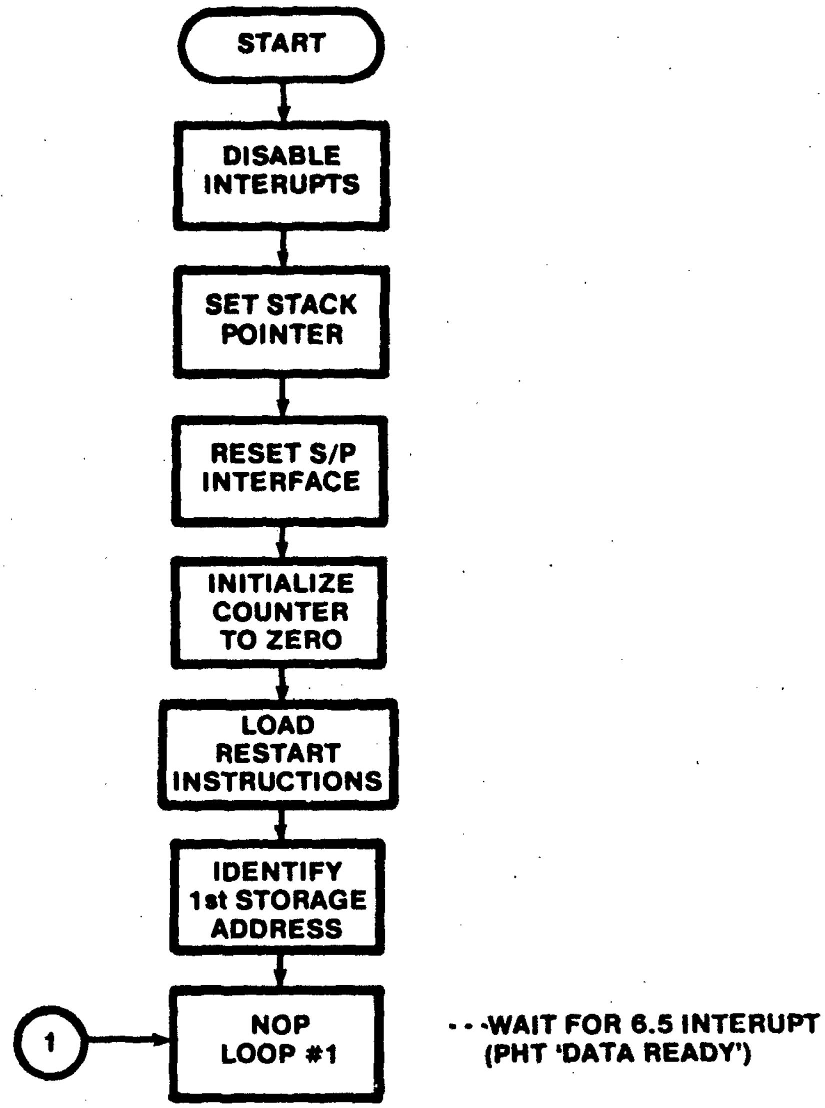


RESULT = SCRATCH1 $\pm$ N * SCRATCH2

```
ISIS-II 8080/8085 MACRO ASSEMBLER, V3.0        SUBS
ADJUST

 LOC  OBJ          LINE        SOURCE STATEMENT

                    414          CSEG
                    415 ADJUST
 008A 110000   E    416          LXI    D,SCRCH1           ;(D,E) CONTAIN ADDRESS OF X
 008D 210000   E    417          LXI    H,SCRCH2           ;(H,L) CONTAIN ADDRESS OF Y
                    418 ;
 0090 17            419          RAL                       ;ROTATE BIT 7 TO CARRY POSITION
 0091 DAAC00   C    420          JC     NEG                ;IF CARRY IS SET, N IS NEGATIVE
                    421 ;
                    422 POS:
 0094 0F            423          RRC                       ;RESTORE ACCUMULATOR
 0095 E61F          424          ANI    1FH                ;REMOVE BITS 7,6,5 (SET RANGE TO 31)
 0097 C8            425          RZ                        ;RETURN IF N = 0
 0098 F5            426          PUSH   PSW                ;SAVE COUNTER ( I )
                    427 XPLUSY:
 0099 CD6F00   C    428          CALL   TBADD              ; Z = X + Y
 009C CD8200   C    429          CALL   STORE1             ;X = Z   ( Z IS STORED AT X'S ADDRESS)
 009F F1            430          POP    PSW                ;
 00A0 3D            431          DCR    A                  ; I = I - 1  (DECREMENT COUNTER)
 00A1 C8            432          RZ                        ;RETURN IF COUNTER = 0
 00A2 F5            433          PUSH   PSW                ; IF COUNTER > 0, THEN
 00A3 110000   E    434          LXI    D,SCRCH1           ;RELOAD X AND Y ADDRESSES
 00A6 210000   E    435          LXI    H,SCRCH2
 00A9 C39900   C    436          JMP    XPLUSY             ;ADD Y TO X AGAIN
                    437 ;
                    438 NEG:
 00AC 0F            439          RRC                       ;RESTORE ACCUMULATOR
 00AD E61F          440          ANI    1FH                ;REMOVE BITS 7,6,5 (SET RANGE TO 31)
 00AF C8            441          RZ                        ;RETURN IF N = 0
 00B0 F5            442          PUSH   PSW                ;SAVE COUNTER (I)
                    443 XMNUSY:
 00B1 CD3200   C    444          CALL   TBSUB              ; Z = X - Y
 00B4 CD8200   C    445          CALL   STORE1             ;X = Z   ( Z IS STORED AT X'S ADDRESS)
 00B7 F1            446          POP    PSW                ;
 00B8 3D            447          DCR    A                  ; I = I - 1 ( DECREMENT COUNTER )
 00B9 C8            448          RZ                        ;RETURN IF COUNTER = 0
 00BA F5            449          PUSH   PSW                ; IF COUNTER > 0, THEN
 00BB 110000   E    450          LXI    D,SCRCH1           ;RELOAD X AND Y ADDRESSES
 00BE 210000   E    451          LXI    H,SCRCH2
 00C1 C3B100   C    452          JMP    XMNUSY             ;SUBTRACT Y FROM X AGAIN
                    453 ;
                    454 $TITLE ('TABLE_SET')
                    455 $EJECT
```

```
ASM80 :F1:PHTMAP SPC DEBUG MOD85

ISIS-II 8080/8085 MACRO ASSEMBLER, V3.0        PHTMAP

 LOC  OBJ        LINE        SOURCE STATEMENT

                         ;
                         ;
                                NAME    PHTMAP
                         ;
                         ;
                         ;
                         ;                    *****************
                         ;                    *               *
                         ;                    *    PHTMAP     *
                         ;                    *               *
                         ;                    *****************
                         ;
                         ;
                         ;
                         ;       THIS PROGRAM IS DESIGNED TO TEST THE POLHEMUS HEAD TRACKER SHMS-III-A IN CONJUNCTION
                         ;      WITH AN INTERFACE BOARD THAT CONVERTS THE PHT'S SERIAL DATA TO PARALLEL DATA
                         ;
                         ;      THE PROGRAM INITIALLY RESETS THE S/P BOARD. WHICH CAUSES A REQUEST FOR POLHEMUS
                         ;      TO CALCULATE A NEW SET OF DATA . THEN A LOOP IS ENCOUNTERED WHERE THE PROGRAM
                         ;      WAITS FOR A DATA READY SIGNAL (6 5 INTEPUPT). WHEN DATA READY IS SENT , THE NEXT
                         ;      PART OF THE PROGRAM STORES A WORD OF DATA  THE WORD STORED DEPENDS ON THE VALUE
                         ;      STORED IN THE C-REGISTER
                         ;
                         ;              00H - HORIZONTAL DATA ( AZIMUTH )
                         ;              01H - VERTICAL DATA ( ELEVATION )
                         ;              02H - ROLL DATA
                         ;
                         ;       THIS STORAGE CONTINUES UNTIL THE RAM USED FOR STORAGE IS FILLED (RAM 2000H - 20FFH )
                         ;      SINCE EACH PHT WORD IS TWO-BYTE THE PROGRAM STORES 128 VALUES OF DATA  AFTER 128 VALUES
                         ;      ARE STORED THE PROGRAM DROPS OUT OF THE STORE MODE AND INTO THE NON-STORE MODE
                         ;      IN THIS MODE , THE SAME TYPE OF DATA, AS INDICATED BY THE C-REGISTER, IS PULLED ONTO THE
                         ;      INPUT PORTS BUT IS NOT STORED  WHEN THIS DATA IS ON THE PORT , THE BIT PATTERN CAN BE
                         ;      READ FROM LED'S ON THE S/P BOARD  IN ORDER TO SEE THESE BIT PATTERNS , A DELAY LOOP IS
                         ;      ENTERED TO WAIT BEFORE PULLING IN NEW DATA, ALLOWING THE DATA TO BE ON THE
                         ;      PORT LONG ENOUGH TO CAUSE THE LED'S TO REMAIN LIGHTED AND TO ALLOW ONE TO SEE THE
                         ;      BIT PATTERN
                         ;
                         ;
                         ;      DEFINE CONSTANTS
                         ;
 05F1                    DELAY  EQU     05F1H                  ;ADDRESS OF MONITOR DELAY ROUTINE
 2000                    COUNT  EQU     2000H                  ;DELAY COUNT VALUE (APPRX      SEC )
 001D                    MASK   EQU     1DH                    ;SIM MASK VALUE
 00FF                    ENDSTO EQU     0FFH                   ;END OF STORAGE VALUE
 2000                    BEGIN  EQU     2000H                  ;BEGINNING OF STORAGE
                         ;
                         ;      DEFINE EXTERNAL VALUES
                         ;
                                EXTRN   RST65B,RST65A,HINPUT,GETELV,RSTSP,STK,FIRST
                         ;
                         $TITLE ('PHTMAP')
                         $EJECT
```

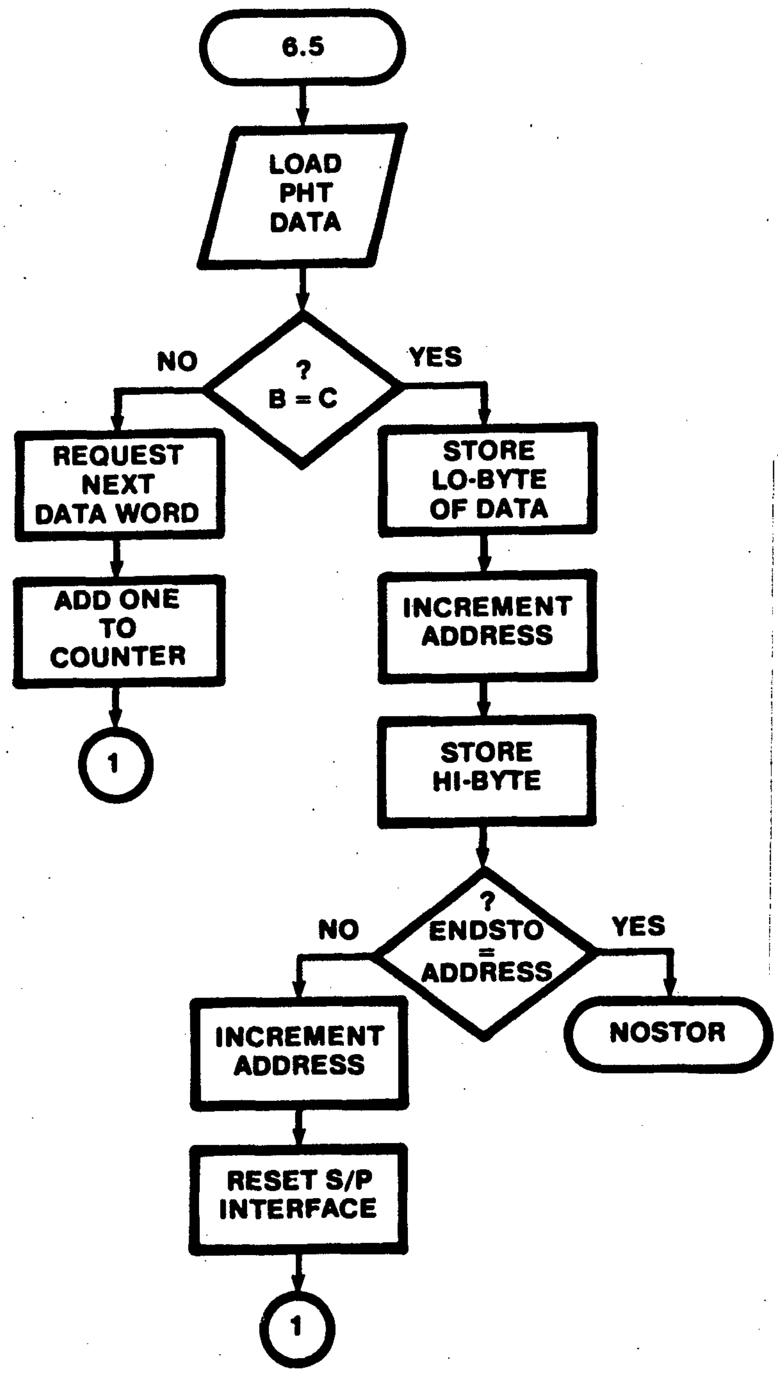
PHTMAP



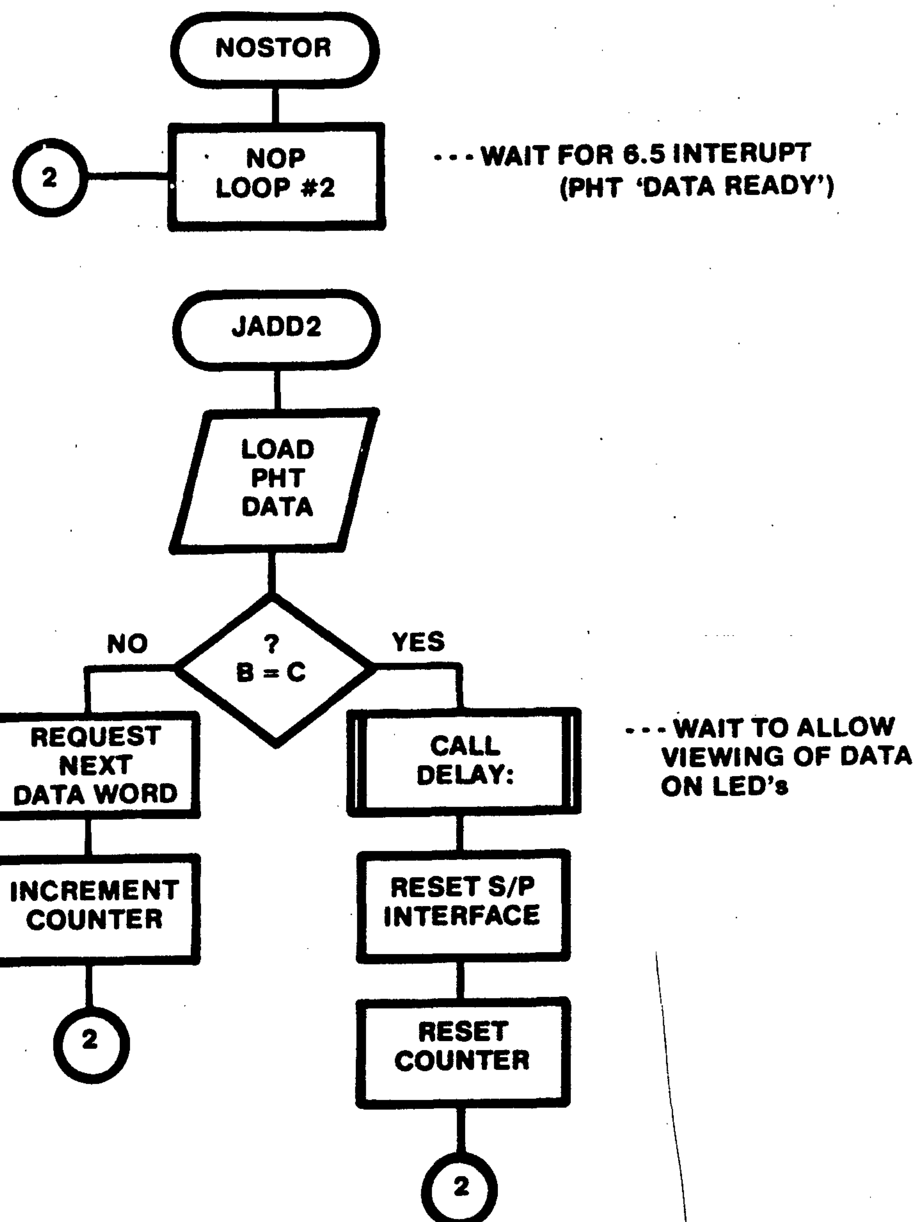
***-NOTE**
TO SELECT ONE OF THE THREE ANGLES (YAW, PITCH, ROLL), A CONSTANT MUST BE LOADED INTO REGISTER C BEFORE RUNNING PHTMAP INDICATING THE ANGLE DESIRED ACCORDING TO:

00HEX - YAW DATA
01HEX - PITCH DATA
03HEX - ROLL DATA

PHTMAP CONT.


6.5
LOAD PHT DATA
? B = C
NO
YES
REQUEST NEXT DATA WORD
ADD ONE TO COUNTER
1
STORE LO-BYTE OF DATA
INCREMENT ADDRESS
STORE HI-BYTE
? ENDSTO = ADDRESS
NO
YES
INCREMENT ADDRESS
RESET S/P INTERFACE
1
NOSTOR

PHTMAP CONT.


NOSTOR
2
NOP
LOOP #2
... WAIT FOR 6.5 INTERUPT
(PHT 'DATA READY')
JADD2
LOAD
PHT
DATA
?
B = C
NO
YES
REQUEST
NEXT
DATA WORD
INCREMENT
COUNTER
2
CALL
DELAY:
... WAIT TO ALLOW
VIEWING OF DATA
ON LED's
RESET S/P
INTERFACE
RESET
COUNTER
2

```
ISIS-II 8080/8085 MACRO ASSEMBLER, V3.0        PHTMAP
PHTMAP

 LOC  OBJ          LINE       SOURCE STATEMENT

                     53        CSEG
                     54 PHTMAP:
 0000 F3             55        DI                      ;DIABLE INTERUPTS
 0001 310000    E    56        LXI     SP,STK          ;SET STACK POINTED
                     57 ;
 0004 320000    E    58        STA     RSTSP           ;RESET SERIAL TO PARALLEL BOARD
                     59 ;
 0007 0600           60        MVI     B,00H           ;INITIALIZE COUNTER (B) TO ZERO
                     61 ;
 0009 210000    E    62        LXI     H,FIRST         ;(H L) CONTAINS DI,JMP INSTRUCTIONS
 000C 220000    E    63        SHLD    RST658          ;STORE 1ST PART OF 6.5 INSTR
 000F 212000    C    64        LXI     H,JADD1         ;(H,L) CONTAINS ADDRESS FOR JUMP
 0012 220000    E    65        SHLD    RST65A          ;STORE 6.5 JUMP ADDRESS
                     66 ;
 0015 110020         67        LXI     D,BEGIN         ;(D,E) CONTAINS 1ST STORAGE LOCATION
                     68 ;
                     69 NOP1:                          ; *** LOOP #1 ***
                     70
 0018 00             71        NOP
 0019 3E1D           72        MVI     A,MASK          ;UNMASK 6.5 INTERUPT
 001B 30             73        SIM
 001C FB             74        EI                      ;ENABLE INTERUPTS
 001D C31800    C    75        JMP     NOP1            ; ** WAIT FOR 6.5 INTERUPT **
                     76 ;
                     77 JADD1:
 0020 2A0000    E    78        LHLD    HINPUT          ;(H,L) GETS INPUT (PULLS DOWN 6.5)
 0023 78             79        MOV     A,B
 0024 B9             80        CMP     C               ;DOES  B = C ?
 0025 CA2F00    C    81        JZ      STORE           ;IF EQUAL, STORE INPUT
                     82 ;
 0028 320000    E    83        STA     GETELV          ;IF NOT EQUAL, REQUEST NEXT WORD OF DATA
 002B C601           84        ADI     01H             ; THEN , ADD 1 TO COUNTER
 002D 47             85        MOV     B,A             ; AND
 002E C9             86        RET                     ; RETURN TO NOP1 LOOP
                     87 ;
                     88 STORE:
 002F EB             89        XCHG                    ;(D,E) CONTAINS INPUT ; (H,L) CONTAINS
                                                       MEMORY ADDRESS
                     90 ;
 0030 73             91        MOV     M,E             ;STORE LO-BYTE OF INPUT
 0031 23             92        INX     H               ;MEM = MEM + 1
                     93 ;
 0032 7A             94        MOV     A,D             ;ACC GETS HI-BYTE OF INPUT
 0033 17             95        RAL
 0034 3F             96        CMC
 0035 1F             97        RAR                     ;COMPLIMENT MSB OF INPUT
 0036 77             98        MOV     M,A             ;AND STORE IN MEMORY
                     99 ;
 0037 3EFF          100        MVI     A,ENDSTO        ;CHECK FOR END OF STORAGE
 0039 BD            101        CMP     L               ; DOES REG. L EQUAL END ?
 003A CA4500    C   102        JZ      NOSTOR          ;IF EQUAL, GO TO NOSTORE MODE
                    103 $EJECT
```

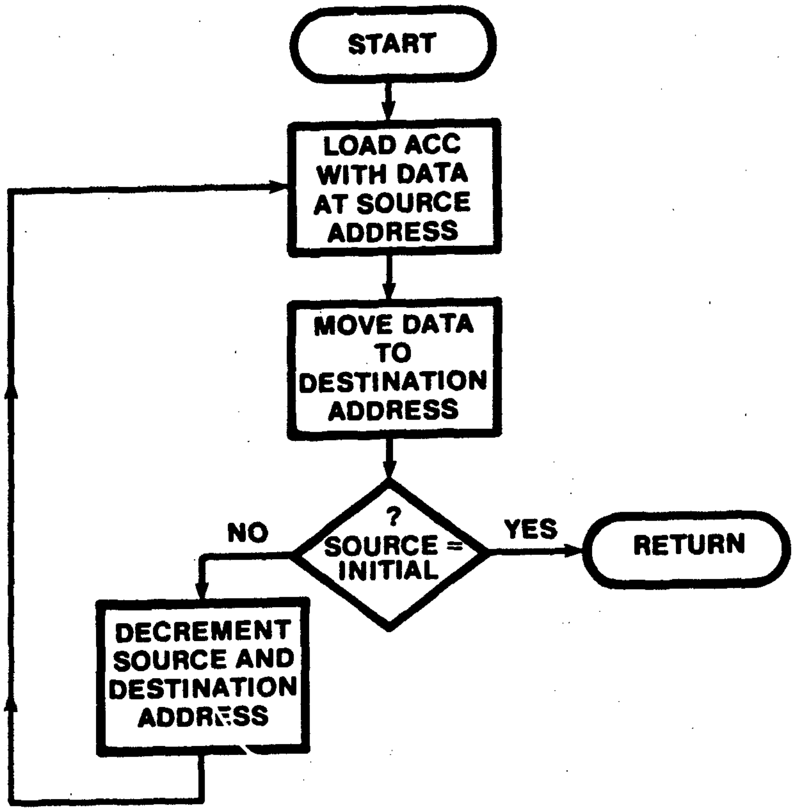
```
ISIS-II 8080/8085 MACRO ASSEMBLER, V3 0        PHTMAP
PHTMAP

LOC  OBJ          LINE      SOURCE STATEMENT

                       ;                                  IF NOT EQUAL ( SET UP FOR MORE STORAGE)
003D 23                        INX     H                  ;MEM = MEM + 1
003E EB                        XCHG                       ;(D,E) POINTS TO MEMORY
                       ;
003F 320000     E              STA     RSTSP              ; RESET SERIAL TO PARALLEL BOARD
                       ;
0042 0600                      MVI     B,00H              ;RESET COUNTER TO ZERO
0044 C9                        RET                        ;RETURN TO NOP1 LOOP
                       ;
                       NOSTOR:
0045 00                        NOP
0046 215A00     C              LXI     H,JADD2            ;(H,L) GETS NEW JUMP ADD FOR 6.5
0049 220000     E              SHLD    RST65A             ;AND THEN IS MOVED TO 6.5 RESTART AREA
                       ;
004C E1                        POP     H                  ;REMOVE NOP1 RETURN ADDRESS
                       ;
004D 0600                      MVI     B,00H              ;RESET COUNTER TO ZERO
                       ;
004F 320000     E              STA     RSTSP              ;RESET SERIAL TO PARALLEL BOARD
                       ;
                       NOP2:                              ; *** LOOP #2 ***
0052 00                        NOP
0053 3E1D                      MVI     A,MASK             ;UNMASK 6.5 INTERUPT
0055 30                        SIM                        ;ENABLE INTERUPTS
0056 FB                        EI                         ; ** WAIT FOR 6.5 INTERUPT **
0057 C35200     C              JMP     NOP2
                       ;
                       JADD2:
005A 2A0000     E              LHLD    HINPUT             ;(H,L) GETS INPUT FROM PHT
005D 78                        MOV     A,B
005E B9                        CMP     C                  ;DOES B = C ?
005F CA6900     C              JZ      DSPLAY             ;IF EQUAL, WAIT BEFORE RESETTING
                       ;
0062 320000     E              STA     GETELV             ;IF NOT EQUAL, REQUEST NEXT WORD OF DATA
0065 C601                      ADI     01H
0067 47                        MOV     B,A                ;INCREMENT COUNTER
0068 C9                        RET                        ;AND RETURN TO NOP2 - LOOP #2
                       ;
                       DSPLAY:
0069 110020                    LXI     D,COUNT            ;(D,E) CONTAINS DELAY COUNT
006C CDF105                    CALL    DELAY              ;WAIT SPECIFIED TIME PERIOD
                       ;
006F 320000     E              STA     RSTSP              ;RESET SERIAL TO PARALLEL BOARD
                       ;
0072 0600                      MVI     B,00H              ;RESET COUNTER
0074 C9                        RET                        ;RETURN TO NOP2 - LOOP #2
                       ;
                       $EJECT
```

```
ISIS-II 8080/8085 MACRO ASSEMBLER, V3.0        PHTMAP
PHTMAP

  LOC  OBJ        LINE       SOURCE STATEMENT

                   152        END

PUBLIC SYMBOLS

EXTERNAL SYMBOLS
FIRST  E 0000   GETELV E 0000   HINPUT E 0000   RST658 E 0000   RST65A E 0000   RSTSP  E 0000   STK    E 0000

USER SYMBOLS
BEGIN  A 2800   COUNT  A 2000   DELAY  A 05F1   DSPLAY C 0069   ENDSTO A 00FF   FIRST  E 0000   GETELV E 0000
HINPUT E 0000   JADD1  C 0020   JADD2  C 005A   MASK   A 001D   NOP1   C 0018   NOP2   C 0052   NOSTOR C 0045
PHTMAP C 0000   RST658 E 0000   RST65A E 0000   RSTSP  E 0000   STK    E 0000   STORE  C 002F

ASSEMBLY COMPLETE,   NO ERRORS
```

ISIS-II 8080/8085 MACRO ASSEMBLER, V3 0   SUBS
FIFO

```
LOC  OBJ        LINE       SOURCE STATEMENT

     ;
     ;
     ;       *****************
     ;       *               *
     ;       *     FIFO      *
     ;       *               *
     ;       *****************
     ;
     ;
     ;        THIS SUBROUTINE IS USED TO SHIFT A TABLE CONTAINING DATA WORDS  DOWN
     ;       IN RAM OVERWRITING THE LAST WORD, BUT PRESERVING THE FIRST WORD
     ;       THE LENGTH OF THE WORDS INVOLVED IS CONSIDERED IN THE INPUT VALUES THAT
     ;       ARE PASSED TO THRE SUBROUTINE.
     ;
     ;       FOR EXAMPLE , CONSIDER THIS TABLE CONTAINING THREE TWO-BYTE WORDS:
     ;
     ; ADDRS  TABLE
     ;
     ; 2000H [_____]  W0-LO     2000H [_____]  W0-LO
     ; 2001H [_____]  W0-HI     2001H [_____]  W0-HI
     ; 2002H [_____]  W1-LO     2002H [_____]  W0-LO
     ; 2003H [_____]  W1-HI     2003H [_____]  W0-HI
     ; 2004H [_____]  W2-LO     2004H [_____]  W1-LO
     ; 2005H [_____]  W2-HI     2005H [_____]  W1-HI
     ;
     ;        BEFORE                   AFTER
     ;        FIFO                     FIFO
     ;
     ;       (D,E) SHOULD CONTAIN THE ADDRESS OF W1-HI (2003H)
     ;       (H,L) SHOULD CONTAIN THE ADDRESS OF W2-HI (2005H)
     ;        B SHOULD CONTAIN THE LO-BYTE ADDRESS OF W0 (2000H)
     ;
     ;
     ;INPUTS:
     ;       (D,E) - CONTAINS THE SOURCE ADDRESS ( ADD. OF HI-BYTE OF NEXT TO LAST WORD)
     ;       (H,L) - CONTAINS THE ADDRESS OF THE HI-BYTE OF THE LAST WORD IN THE TABLE
     ;         B   - CONTAINS THE ADDRESS OF THE FIRST TABLE LOCATION
     ;     ** - THIS ROUTINE CANNOT SHIFT TABLES THAT CROSS HI-BYTE ADDRESS BOUNDRIES.
     ;
     ;OUTPUT:
     ;       THE DESCRIBED TABLE IS SHIFTED.
     $EJECT
```

FIFO



INPUT: (D, E) ← SOURCE ADDRESS
(H, L) ← DESTINATION ADDRESS
B ← INITIAL ADDRESS

OUTPUT: TABLE IS SHIFTED DOWNWARDS IN RAM (NUMBER OF LOCATIONS MOVED IS IMPLIED BY DIFFERENCE BETWEEN SOURCE AND DESTINATION ADDRESSES)

```
ISIS-II 8080/8085 MACRO ASSEMBLER, V3.0          SUBS
FIFO

 LOC  OBJ          LINE        SOURCE STATEMENT

                    535 ;
                    536         CSEG
                    537 FIFO:
 00CD 1A            538         LDAX    D                    ;LOAD ACC WITH DATA AT SOURCE ADDRESS
 00CE 77            539         MOV     M,A                  ;MOVE SOURCE DATA DOWN TWO POSITIONS
                    540 ;
 00CF 78            541         MOV     A,B                  ;MOVE ADD OF FIRST WORD TO ACC
 00D0 BB            542         CMP     E                    ;AND COMPARE WITH SOURCE ADDRESS
 00D1 C8            543         RZ                           ;RETURN IF FIRST WORD HAS BEEN MOVED
                    544 ;
 00D2 1B            545         DCX     D                    ;IF MORE TO SHIFT, POINT TO NEXT SOURCE
 00D3 2B            546         DCX     H                    ;AND DESTINATION ADDRESS
 00D4 C3CD00    C   547         JMP     FIFO                 ;THEN SHIFT NEXT PIECE OF DATA
                    548 $EJECT
```

```
ISIS-II 8080/8085 MACRO ASSEMBLER, V3 0        SUBS
TABLE_SET

 LOC  OBJ          LINE        SOURCE STATEMENT

                    456 ;
                    457 ;
                    458 ;        ****************
                    459 ;        *              *
                    460 ;        *    TBLSET    *
                    461 ;        *              *
                    462 ;        ****************
                    463 ;
                    464 ;         THIS SUBROUTINE IS USED TO FILL A GROUP OF RAM LOCATIONS WITH AN INITIAL VALUE
                    465 ;        WORD WHICH IS TWO-BYTES LONG.
                    466 ;
                    467 ;INPUTS:
                    468 ;        (D,E) - CONTAINS THE INITIAL VALUE
                    469 ;        (H,L) - CONTAINS THE FIRST ADDRESS FOR INITIALIZATION
                    470 ;         ACC  - LO-BYTE OF FINAL ADDRESS IN THE TABLE
                    471 ;     ** -  TABLE CANNOT EXTEND ACROSS THE HI-BYTE BOUNDRY
                    472 ;
                    473 ;OUTPUT:
                    474 ;        RAM LOCATIONS FROM THE FIRST ADDRESS TO THE FINAL ADDRESS ARE FILLED
                    475 ;        WITH THE INITIAL VALUE IN (D,E)
                    476 ;
                    477 ;
                    478          CSEG
                    479 TBLSET:
00C4 73             480          MOV     M,E                 ;MOVE LO-BYTE INITIAL VALUE TO (H,L) ADDRESS
00C5 23             481          INX     H                   ;INCREMENT (H,L) ADDRESS
00C6 72             482          MOV     M,D                 ;MOVE HI-BYTE INITIAL VALUE TO (H,L) ADDRESS
                    483 ;
00C7 BD             484          CMP     L                   ;CHECK FOR END OF TABLE
00C8 C8             485          RZ                          ;RETURN IF AT END OF TABLE
                    486 ;
00C9 23             487          INX     H                   ;IF NOT AT END INCREMENT (H,L)
00CA C3C400    C    488          JMP     TBLSET              ;INITIALIZE NEXT TWO BYTES
                    489 ;
                    490 ;
                    491 $TITLE ('FIFO')
                    492 $EJECT
```

```
ISIS-II 8080/8085 MACRO ASSEMBLER, V3.0        SUBS
MAX

 LOC  OBJ         LINE        SOURCE STATEMENT

                         ;
                         ;        ****************
                         ;        *              *
                         ;        *     MAX      *
                         ;        *              *
                         ;        ****************
                         ;
                         ;
                         ;        THIS SUBROUTINE COMPARES A TWO-BYTE WORD WITH A ONE-BYTE WORD (MAX)
                         ;        IF THE TWO-BYTE WORD IS GREATER THAN THE MAX WORD, THEN THE MAX
                         ;        WORD IS RETURNED TO THE CALLING PROGRAM. IF THE TWO-BYTE WORD IS LESS
                         ;        THAN THE MAX WORD, THEN THE LO-BYTE OF THE TWO-BYTE WORD IS RETURNED
                         ;        TO THE CALLING PROGRAM.
                         ;
                         ;
                         ;INPUTS:
                         ;        ACC   - CONTAINS THE MAXIMUM VALUE ( ONE-BYTE )
                         ;        (H,L)- CONTAINS THE TWO-BYTE WORD FOR COMPARISON
                         ;
                         ;OUTPUT:
                         ;        B - CONTAINS THE LESSOR OF THE MAXIMUM VALUE OR THE TWO-BYTE WORD
                         ;
                         ;
                                  CSEG
                         MAX:
                         ;
0078 47                           MOV     B,A                      ;B GETS MAXIMUM VALUE
                         ;
0079 7C                           MOV     A,H                      ;ACC GETS HI-BYTE C-VALUE
007A FE00                         CPI     00H                      ;IF HI-BYTE IS NOT ZERO,
007C C0                           RNZ                              ;RETURN WITH MAX IN B
                         ;
007D 7D                           MOV     A,L                      ;ACC GETS LO-BYTE C-VALUE
007E B8                           CMP     B                        ;COMPARE WITH MAXIMUM
007F D0                           RNC                              ;RETURN IF L IS GREATER THAN MAXIMUM
                         ;
0080 45                           MOV     B,L                      ;ELSE MOVE L TO B
0081 C9                           RET                              ;RETURN WITH LESSOR VALUE IN B
                         ;
                         ;
                         $TITLE ('STORE1')
                         $EJECT
```

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APPENDIX B

RHMC HARDWARE

An Intel SDK-85 development board is used as the micro-controller for the RHMC system -- primarily because it provides a ready-made micro system at a reasonable cost. The microprocessor is an Intel 8085A, which is capable of addressing only 512 bytes of RAM, 2000 bytes of monitor ROM and 2000 bytes of Erasable Programmable Read Only Memory (EPROM). The 8085A is in communication with an in-house designed board which provides two digital to analog converter (DAC) channels for raster shift, EPROM for RHMC program storage, address decoders, and vertical sync for both the Polhemus Head Tracker (PHT) and the microprocessor. In addition, the system contains the Polhemus head tracker (PHT) data controller which allows head pointing direction (HPD) data transfer from the PHT to the microprocessor, and a separate data buffer board than enables the CIG system to take in HPD data transparent to the operation of the 8085 microprocessor system. Figure B1 shows a block diagram of the RHMC and interface hardware.

The PHT data controller (see schematic and timing diagram) controls the format and the distribution of Head Pointing Direction data from the Polhemus Head Tracker. About 15.5 ms. after the sync signal (vertical sync) is sent to the PHT, initiating its position sampling sequence, the PHT indicates that the data is ready by sending, appropriately, a "data ready" pulse to the data controller. The PHT orientation and positional data is then ready to be clocked out of the serial port. A "data acknowledge" signal is returned to the PHT by the controller and a 500 kHz. burst consisting of 17 clock pulses is also sent which clocks out the first 17-bit word, "yaw." This serial string of bits is clocked into dual, 10-bit, serial in, parallel out shift registers. At the end of the 17th clock pulse, the clock is inhibited, and the first 16 bits of the 17-bit word are transferred to dual 8-bit data buffers. These buffers, when full, send an interrupt (Rst. 6.5) to the 8085 microprocessor. The micro, meanwhile, has been patiently waiting in a loop for the data. Upon receipt of the Rst. 6.5 interrupt, the micro addresses the buffers and pulls the data into memory for future processing. The micro writes to memory location (8xx2) which sends a "get data" pulse to the controller and the micro returns to the loop to await further data. Again, the controller sends out a burst of 17 pulses, clocking in the next word, "pitch." In the same sequence as before, the 8085 stores this next word and requests the roll data. At the end of this sequence, "data acknowledge" is cleared and the 8085 begins the computation cycle which eventually determines the 8-bit values sent to the horizontal and vertical, raster shifting, digital to analog converters (HDAC and VDAC). These values are latched into the DACs during the vertical retrace of the laser video projector. Vertical sync (or retrace) is acknowledged as a 7.5 interrupt by the microprocessor.

Again returning to the system block diagram in Figure B1, the offset signals from the HDAC and VDAC are routed to summing circuits; a summer feeding the VCO for the horizontal shift, and a summing point within the scanner controller for the vertical shift.

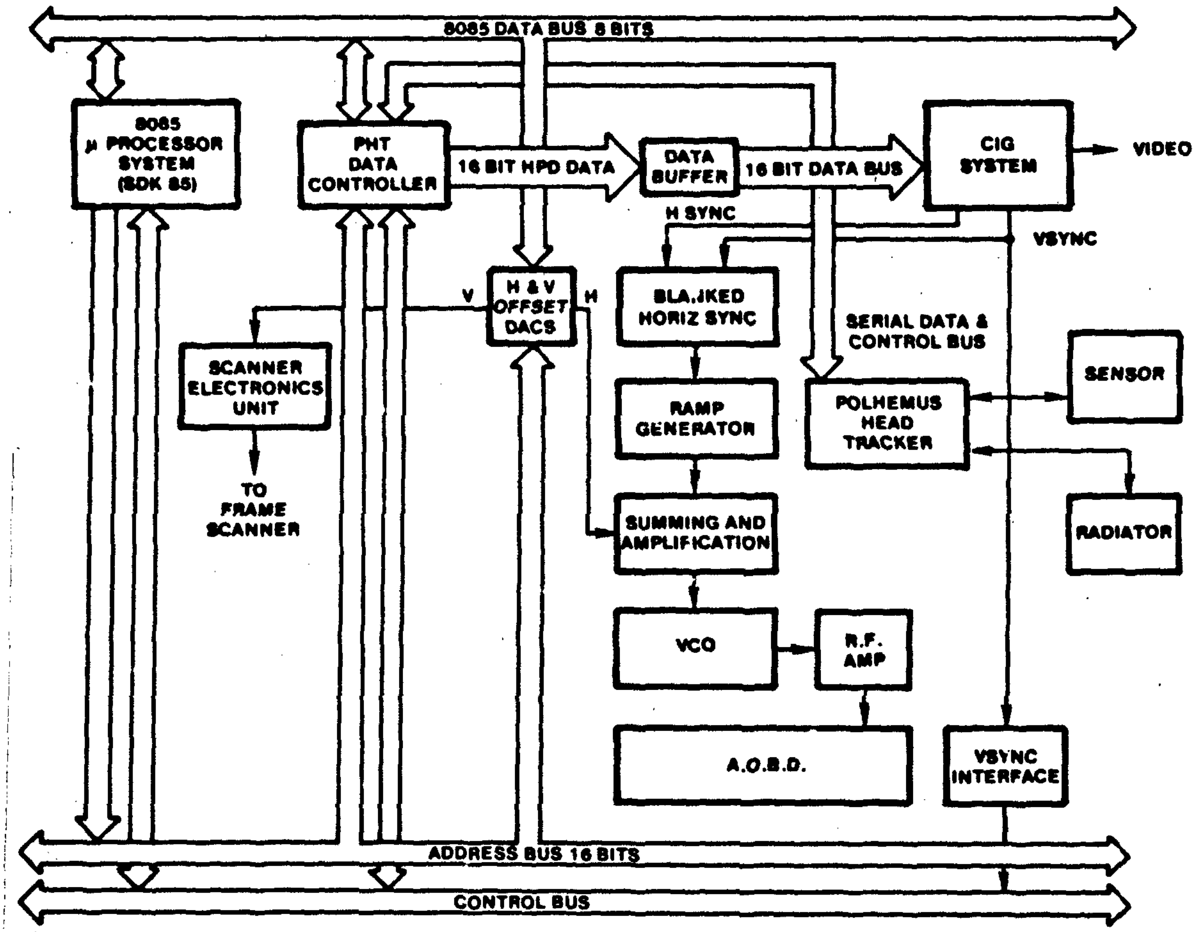
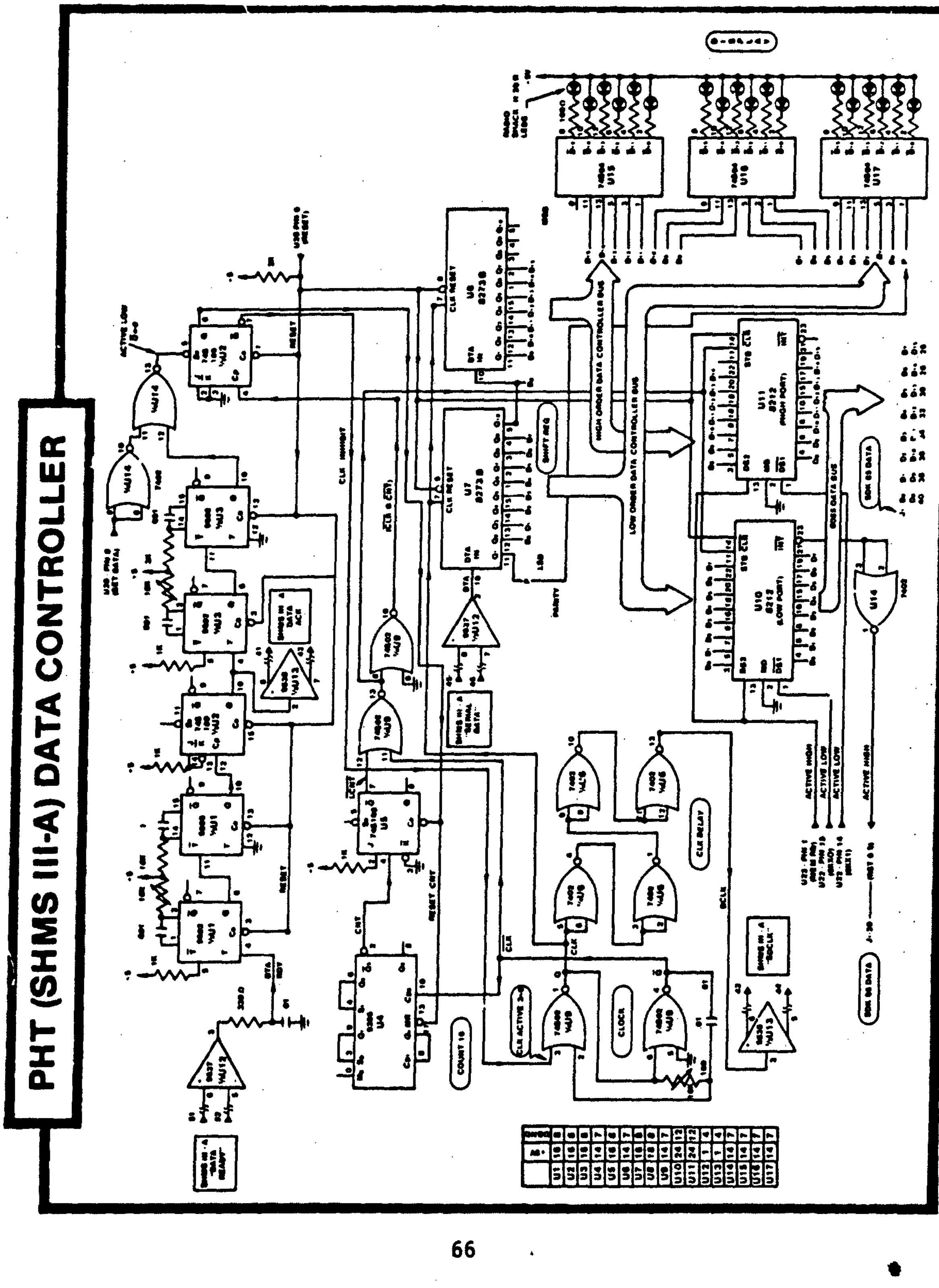


Figure B1. RHMC and Interface Hardware.

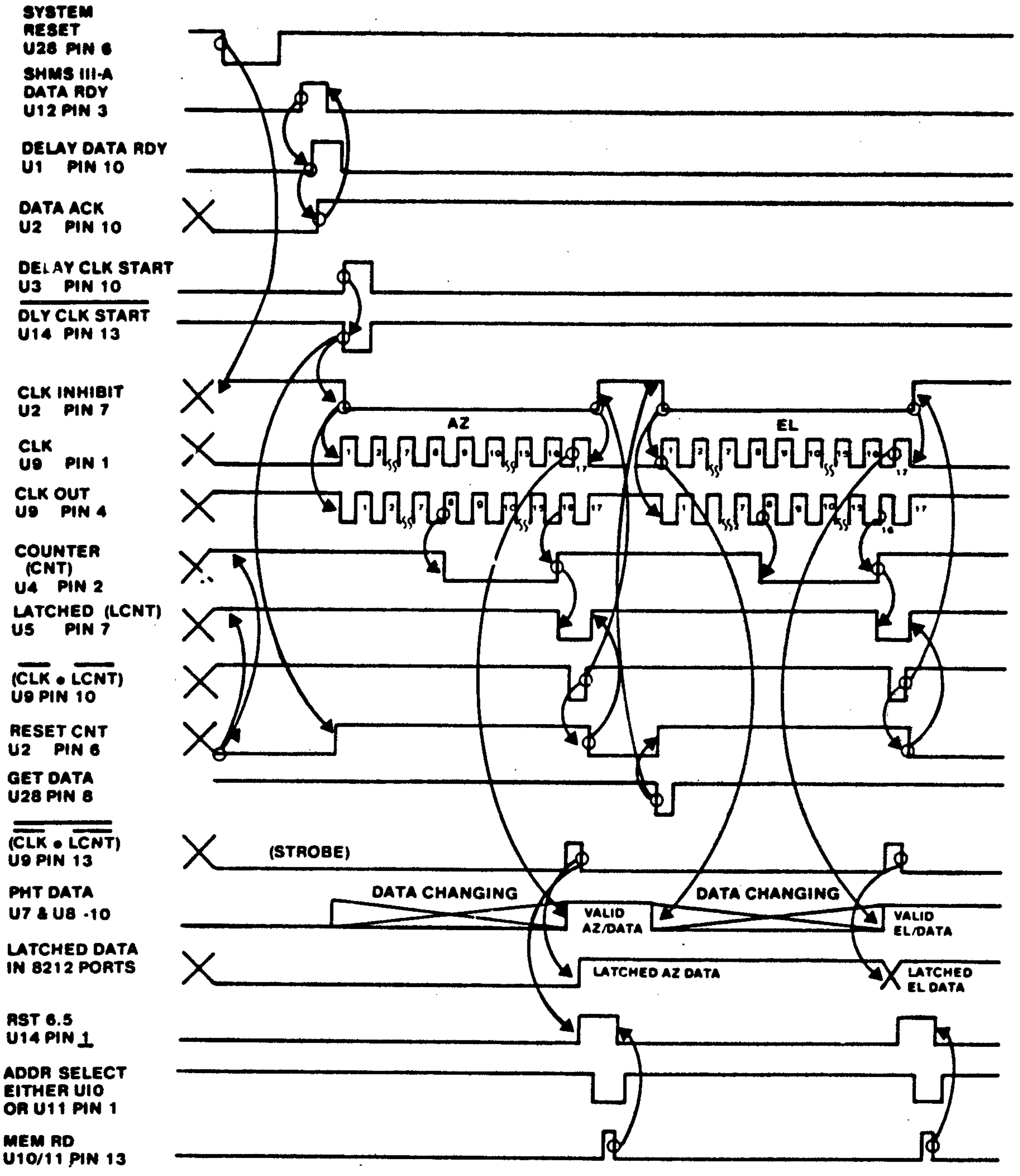
The horizontal offset signal from the HDAC is summed with the output of the ramp generator. The voltage shift of this signal frequency shifts the voltage controlled oscillator which outputs a frequency chirp centered at 375 mHz. Spanning some 200 mHz., the frequency chirp can be shifted up or down in frequency as much as 25 mHz. After suitable amplification, the Acousto Optic Beam Deflector (AOBD) receives the shifted chirp and shifts the horizontal line scan accordingly. The voltage controlled oscillator (VCO) is required to output a chirp, or frequency sweep at a horizontal line rate. As previously mentioned, the VCO is a non-linear device when operated at these line rates (15 to 30 kHz.). Since the VCO is non-linear, its driving signal must be carefully selected and conditioned to achieve a linear output, i.e., a linear frequency chirp. A linear frequency chirp applied to the AOBD results in a sharply focused, linear horizontal sweep. The task of providing a linear frequency chirp is difficult enough; providing a signal which produces a shiftable linear frequency chirp at the output of the VCO proved to be impossible. The subsequent non-linearity produces noticeable display distortion, reducing both the resolution and linearity of the display.

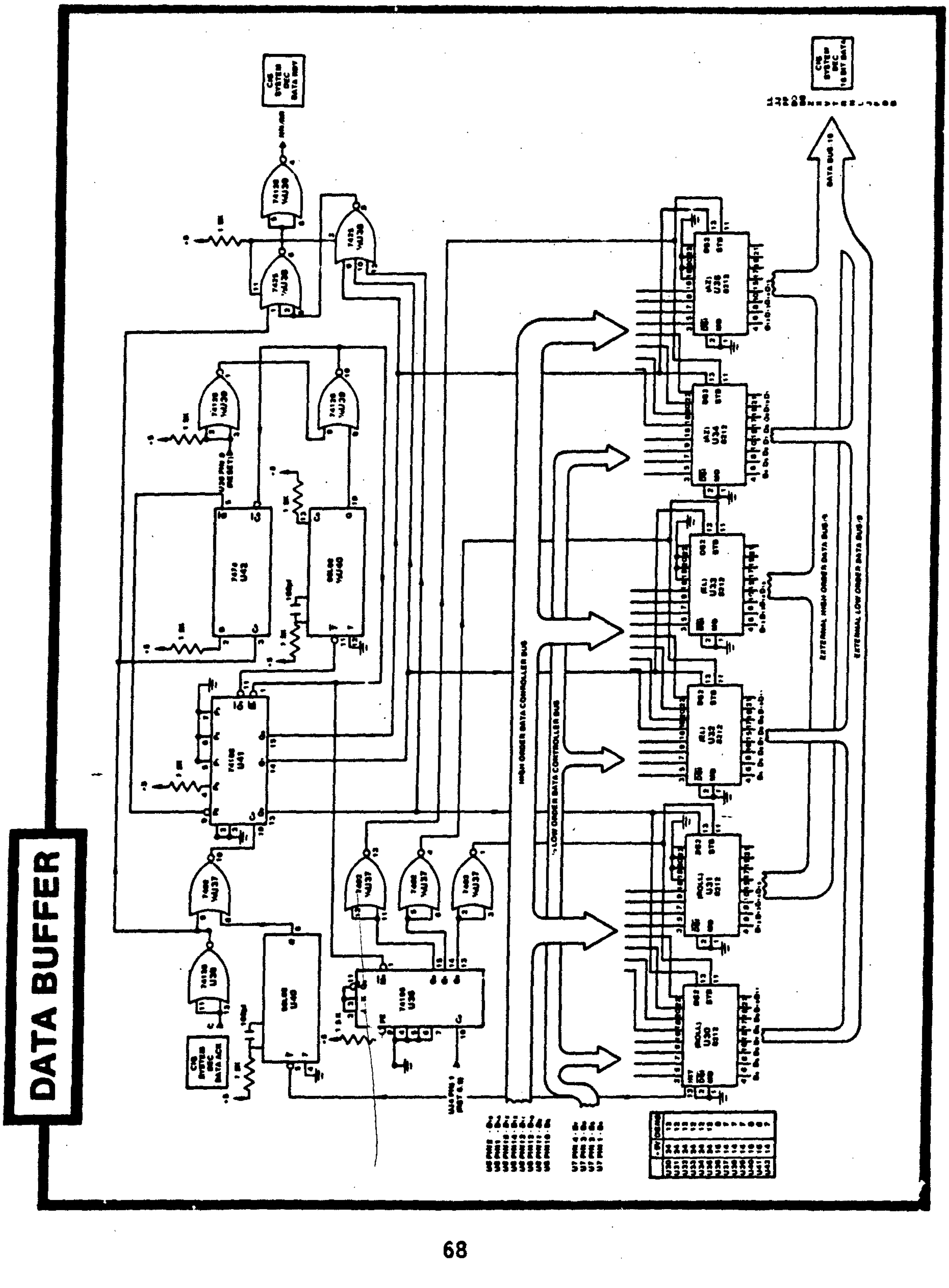
A minor modification of the scanning controller, which drives the frame scanner, allows the vertical offset signal from the VDAC to shift the angle at which the frame scanner begins its vertical scan. This provides the required vertical raster shift.

Both the CIG and RHMC system require head pointing direction (HPD) data every field (16.7 ms.). The data buffer (see schematic and timing diagram) allows the CIG to take in HPD data relatively independent of the operation of the RHMC system. It holds the pitch, roll and yaw data until the CIG sends a request for data. Basically, the data buffer counts the number of Rst. 6.5 interrupts emitted by the PHT data controller and loads one of three 16-bit buffers on each rising edge. When the third buffer has been loaded with data from the PHT data controller bus, a "data ready" is sent to the CIG system indicating that a complete set of HPD data is ready to be transferred, and the first data word, azimuth, is placed on the 16-bit CIG/buffer bus. When the CIG system accepts the data, it returns a "data acknowledge," which places the next data word, elevation, on the bus. This action, in turn, sends another "data ready" to the CIG system. When the final data word, roll, is received by the CIG, and a "data acknowledge" is returned, the three buffers are cleared. The data buffer is then ready for another set of HPD data.

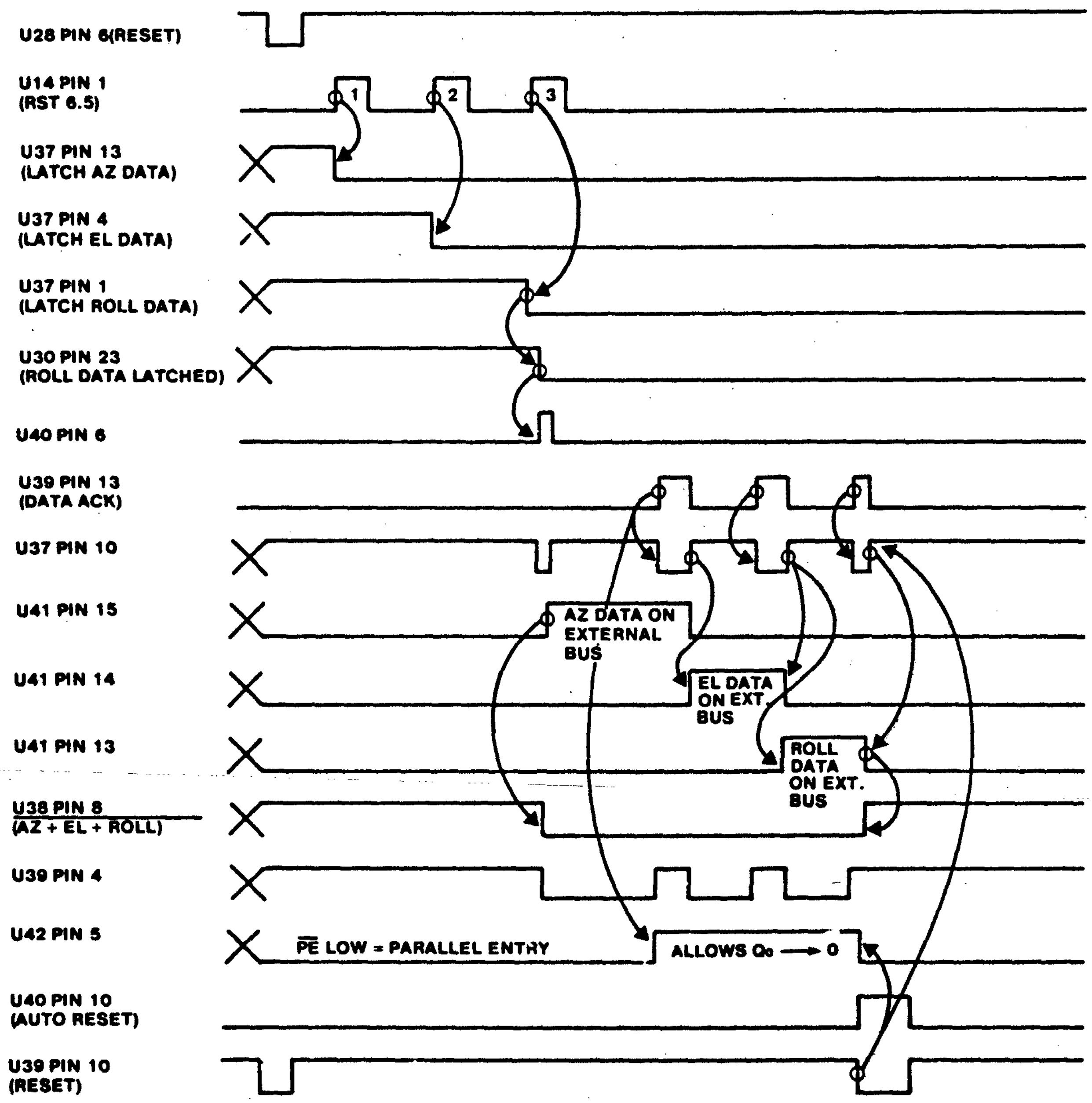

PHT (SHMS III-A) DATA CONTROLLER

PHT (SHMS III) DATA CONTROLLER TIMING DIAGRAM

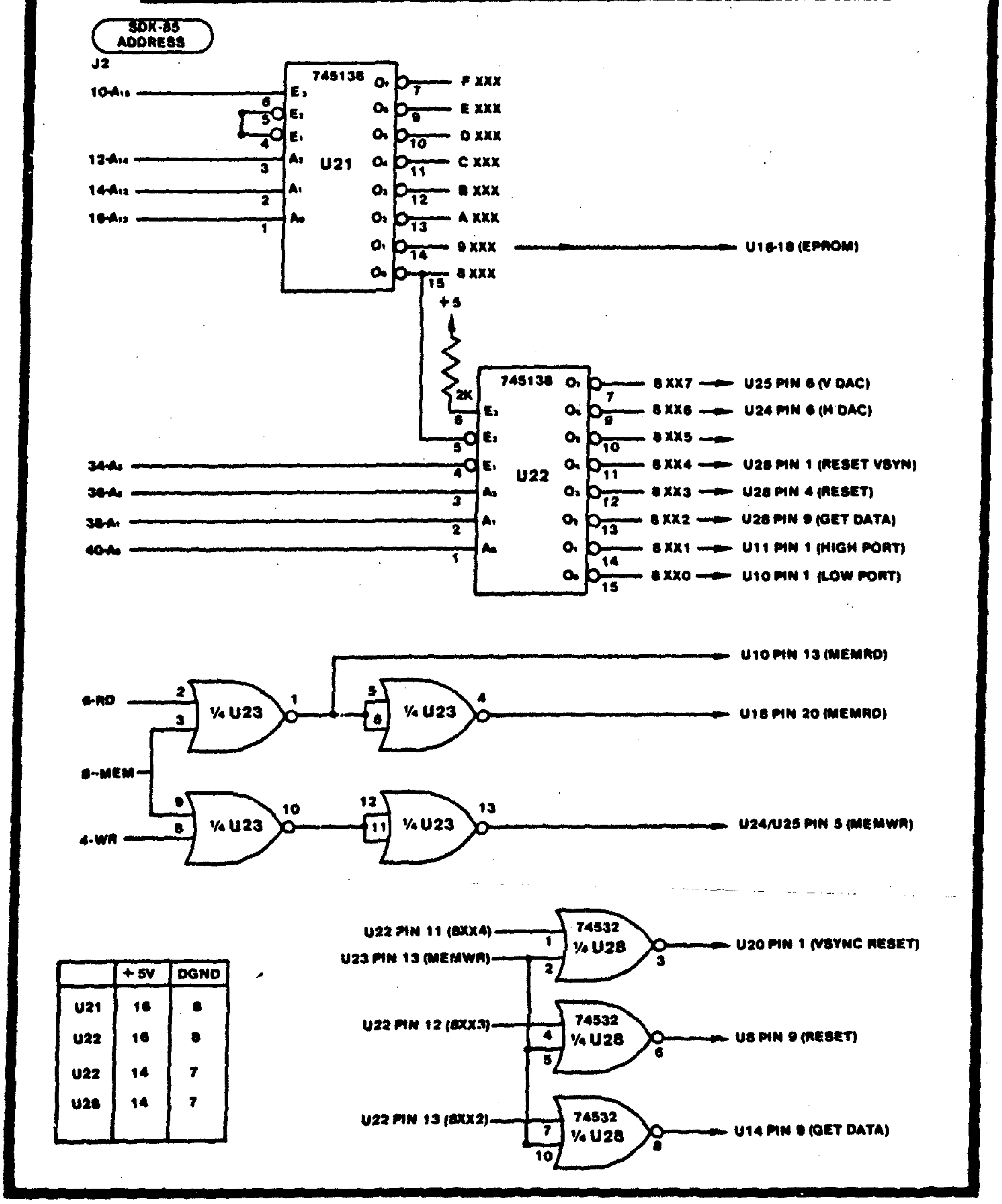



DATA BUFFER

DATA BUFFER TIMING DIAGRAM

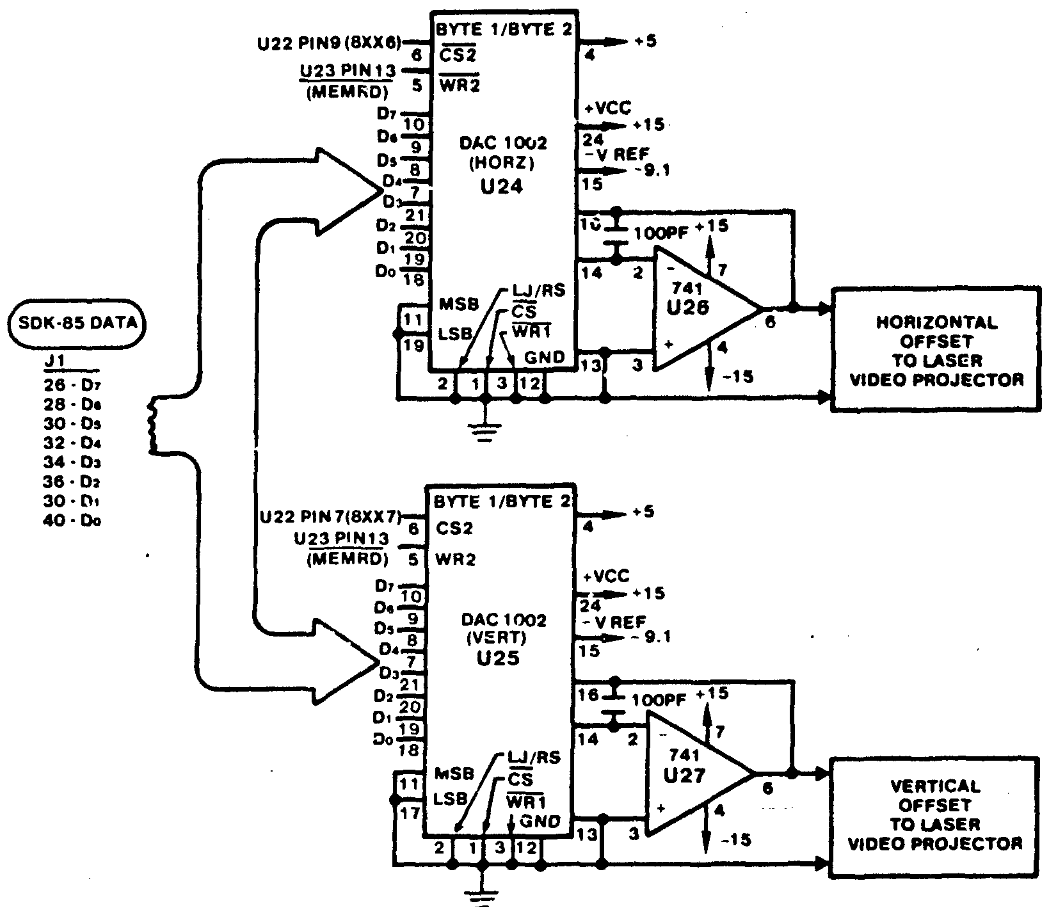


ADDRESS DECODE AND CONTROL

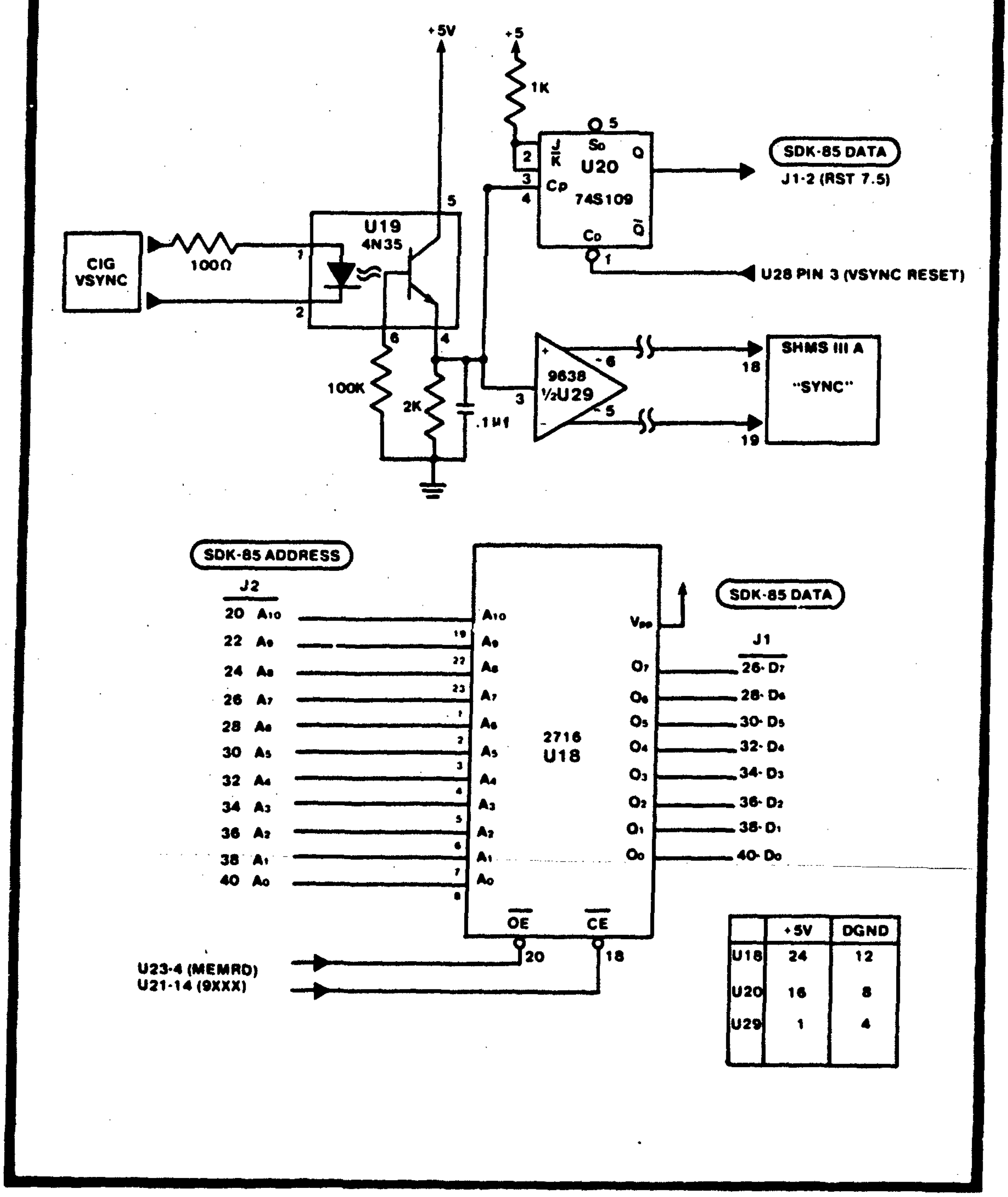


	+5V	DGND
U21	16	8
U22	16	8
U22	14	7
U28	14	7

HORIZONTAL AND VERTICAL OFFSET DAC'S



VSYNC INTERFACE/2K EPROM



	+5V	DGND
U18	24	12
U20	16	8
U29	1	4

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